AD-A084 146 ILLINOIS UNIV AT URBANA-CHAMPAIGN HUMAN ATTENTION RES--ETC F/G 5/10

AUTOMATIC AND CONTROLLED PROCESSING OF SEQUENCES OF EVENTS.(U)

AUG 79 R EBERTS N00014-78-C-0012

UNCLASSIFIED 7901 NL

1 OF 1

AD A084146

END

DATE FILMED

6-80

DTIC

AUTOMATIC AND CONTROLLED PROCESSING OF SEQUENCES OF EVENTS

LEVEL

Ray Eberts

12

REPORT No. 7901

ADA084146

DTIC
SELECTE
MAY 1 4 1980
S C

HUMAN ATTENTION RESEARCH LABORATORY

Psychology Department
University of Illinois
Champaign, Illinois 61820

This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N000014-78-C-0012, Contract Authority Identification No. NR 150-409.

DDC FILE COPY

80 5 12 018

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 7901 (14)	2. GOVT ACCESSION NO. AD-A084 146	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Automatic and controlled processing of sequences of events. (6)		5. TYPE OF REPORT & PERIOD COVERED (9) Technical Report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Ray Eberts		8. CONTRACT OR GRANT NUMBER(s) (15) N00014-78-C-0012
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology University of Illinois		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 150-409
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research Code (458) Arlington, VA 22217		12. REPORT DATE (11) Aug[redacted]79
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 69		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

target detection, overlearning, visual perception, automatic processing, control processing, temporal sequence search, skill development

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) ~~(short form)~~

The characteristics of visual sequences of events that change spatially and temporally are explored. Literature on visual and auditory attention is reviewed with emphasis on spatial and temporal phenomena. A sequence of events in these experiments consisted of three line segments that occur sequentially. A multiple regression study of a sample of 35 sequences indicated that, of several variables analyzed, the angle between successive lines was a fairly good predictor of the ability of subjects to detect a target sequence.

(over)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411750

20. Utilizing sequences of intermediate difficulty, initial experiments evaluated performance of unpracticed subjects. There was a deficit in performance as the number of channels is increased. In later experiments, subjects were well-practiced in consistent mapping (CM) and varied mapping (VM) conditions. In the CM conditions automatic processing was developed and showed qualitatively different performance from VM sequence search. CM search appeared to incorporate motion cues, VM did not. Best performance appeared in CM conditions at relatively fast stimulus durations which optimized apparent motion. In VM slower durations which eliminated the motion cues were best. Other experiments show CM stimuli are easier to rotate. Subjects appear to identify whole patterns, such as motion, for CM sequences and single lines for VM sequences. Finally, there was little effect of processing load for CM sequences, but large load effects for VM sequences when the channel size was doubled.

The Automatic and Controlled Processing

of Sequences of Events

Ray Eberts

University of Illinois, Urbana-Champaign

August, 1979

Abstract

The characteristics of visual sequences of events that change spatially and temporally are explored. The previous literature on visual attention to single events and auditory attention is reviewed with emphasis on spatial and temporal phenomena. Some previous work on visual patterns indicated that motion might be a salient cue in the discrimination of the patterns. A sequence of events in this series of experiments consisted of three line segments that occur sequentially. Stimuli were constructed to enhance optimal motion and to eliminate eye movements and peripheral identification. A multiple regression study of a sample of 35 sequences indicated that, of several variables analyzed, the angle between successive lines was a fairly good predictor of the ability of subjects to detect a target sequence. The distance between lines was a very poor determinant of error rate. Utilizing sequences of intermediate difficulty, initial experiments evaluated performance of unpracticed subjects. The results were similar to auditory monitoring experiments: there is a deficit in performance as the number of channels is increased. The last six experiments employ techniques similar to those used by Schneider and Shiffrin (1977) to determine if sequences of events can be automatically processed. Subjects were well-practiced in consistent mapping (CM) and varied mapping (VM) conditions. An automatic process, which is qualitatively different from performance noticed for the VM sequences, appears to have developed for the CM sequences. A possible qualitative difference between CM and VM sequences was the differential use of motion cues. Best performance appeared in CM conditions at relatively fast stimulus durations which optimized apparent motion. In VM conditions, performance was best at the slower durations which eliminated the motion cues. Also, it was generally easier to rotate CM trained sequences than VM trained. A rotation preserves the relationships between events and changes the single lines. This implies that subjects try to identify whole patterns, such as motion, for CM sequences and single lines for VM sequences. Finally, there was little effect of processing load for CM sequences, but large load effects for VM sequences when the channel size was doubled.

Sequences of Events

I. Introduction

Many of the ideas for present research in cognitive psychology came from work started in the early 1950's on auditory attention. This work led to the rediscovery of attention which directly resulted in research on divided attention and focused, or selective, attention. From this experimentation, two basically different and mutually exclusive modes of information processing were hypothesized - serial and parallel. The type of processing utilized is a question that still persists at this time. Furthermore, this early research led to the development of mechanistic models of attention, the filter models, and this in turn triggered current theories of information processing in cognitive psychology.

It has been tacitly assumed that the attention mechanisms are the same for both audition and vision. Researchers implicitly compare the two, but very few studies have been done that explicitly compare them.

The previous work in visual perception has looked at how humans react to a single event, such as a tachistoscopic flash. An extension of this approach is needed. In auditory attention, stimuli are perceived as a spatial and temporal pattern. Thus, the stimuli used in a visual counterpart that examines attention mechanisms devised by studies done in the auditory modality should also change in both space and time. In addition, people in the real world do not usually respond to just a single event. When driving a car, a sequence of events must be responded to that varies in both space and time. A radar operator must respond to a spatial and temporal pattern on the radar screen. If an analogy from the laboratory to the real world is to be made, the components of space and time in visual perception cannot be ignored.

Recently Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) identified important variables that led to the development of a certain kind of skilled behavior - the automatic processing of visual stimuli. They found qualitative and quantitative differences between what was termed an automatic process and a control process. Differences discovered between the two processes included certain developmental characteristics and the kind of processing utilized for each; serial or parallel. When applying this work to the perception of spatial and temporal patterns, several questions immediately present themselves. Can an automatic process be developed to sequences of events that vary in both time and space? Can qualitative and quantitative differences, similar to ones established by Schneider and Shiffrin, be found between sequences that are trained to be processed automatically and those trained to be control processed? What are some of the characteristics of development of automatic sequences? These questions will be considered in the research that follows.

Finally, since stimuli that change in space and time are being investigated, we must contend with a further area of research - that on apparent motion. An extensive literature exists in this area, dating from the earliest work of the Gestalt psychologists. Research in this area can help guide the choice of stimuli. The apparent motion literature suggests that attention can be directed toward the particular motion configuration instead of the single events. This is an hypothesis that will be explored in detail.

The overall goal of this research is to bring together four areas of research - visual attention, auditory attention, skilled behavior, and apparent motion - into one series of experiments. These four areas are not necessarily disparate. They are highly interrelated, and the need exists for a coherent and integrative treatment.

The next chapter is a rather detailed discussion of auditory attention, visual attention, automatic and controlled processes, and apparent motion. The reader may wish to skip to chapter III entitled "Display Characteristics and Classification." This chapter explains how the stimuli were chosen and includes a multiple regression analysis which tries to identify the important variables that make identification of the three event sequences easy. The next two chapters report nine experiments on the automatic and controlled processing of the sequences. Finally, chapter VI is an overall discussion of the results and how they apply to our previous knowledge of automatic processing of visual stimuli.

II. Background

A. Auditory Perception

The most important component of an auditory event is its temporal aspect (for introductory treatments of elementary acoustics see Neisser, 1967, and Broadbent, 1971). It is perhaps fitting for the development of this thesis to start with a quote from Neisser's (1967, p.174) Cognitive Psychology. He states, "The important point [in acoustics] is that the auditory input consists of a sequence of events." These sequences of events can be characterized in the following way. Sound is composed physically of wave forms that can vary in intensity and frequency. Psychologically, these two components roughly correspond to what we perceive as loudness and pitch, respectively. Thus, when waves impinge upon an organ in the middle ear called the cochlea, the information can be completely described by its intensity, its frequency and their spacing in time. Sound is a complex pattern that varies temporally and spatially.

Historically, attentive processes have been studied using auditory instead of visual stimuli. Both Kahneman (1973) and Broadbent (1971) discuss the reasons for this. Using the auditory mode, attentive processes can be studied without the encumbrance of orientation movements which dominate visual attention. In audition, the listener must rely on the central mechanisms of attention. In vision, attention can be directed to an event by eye movements. Thus, a basic requirement of a series of experiments on visual attention is that a method be devised which does not allow eye movements. Further, the periphery plays an important part in vision. Items are perceived more accurately if they fall on the fovea than in the periphery. Therefore, another basic requirement for a visual attention study is that all items fall in the same relative area of the retina. Kahneman (1973) states that the emphasis upon audition in attention has allowed a limited theoretical treatment of the problem. The need exists for a fuller treatment of attention and the derivation of a method in visual perception that overcomes some of the research problems inherent in the visual

mode.

Reviews of auditory attention exist in several places (Broadbent, 1958, 1971; Neisser, 1967; Treisman, 1969; Moray, 1969; Kahneman, 1973; and Shiffrin and Schneider, 1977). Two kinds of tasks, shadowing and monitoring, are used to study two phenomena of attention - focused attention and divided attention. A central research question seems to be concerned with finding under what conditions information will be processed in parallel or processed serially. Models have been devised which postulate that a sort of bottleneck in the information processing system occurs. The information is processed in parallel up to that bottleneck which then forces a serial process. The locus of this bottleneck - early, middle, or late - has been the source of much discussion and debate between the three major models of attention: Broadbent (1958), Treisman (1960; 1969), and Deutsch and Deutsch (1963). The shadowing and monitoring tasks were devised to try to find the locus of the bottleneck.

Cherry (1953) was the first to use the shadowing technique. In a typical experiment, different messages are presented to the two ears. Subjects are required to ignore one, and to shadow the other. To shadow, they are to repeat back, as soon as possible, the message on the attended ear. To do the task successfully, then, subjects must have the ability to focus their attention to a message on the one ear and ignore the other.

Even though instructed to ignore the message, some of the information on the non-attended ear is noticed by the subjects. It is assumed that this kind of information is processed in parallel before the bottleneck occurs. Research has shown that: 1) subjects are aware of physical changes on the non-attended ear such as a change of voice, a switch from voice to tone, and isolated sounds (Lawson, 1966; Treisman and Riley, 1969; and Cherry, 1953); 2) subjects are aware of the sex of voice on a non-attended channel (Cherry, 1953); and 3) subjects are aware of the occurrence of their own name and certain fright words (Moray, 1969). Treisman (1964a) has shown that some semantic information is processed in parallel. In her experiments she found that if the same message is played to the two ears, subjects will notice the similarity if the lag or lead time is short enough. Treisman (1960) also showed that if a message is switched from one ear to the other, shadowing will follow the semantic information to the non-attended ear very briefly.

Some of the information on the non-attended ear does not get through. It is assumed that this kind of information can only be processed after the location of the bottleneck and must therefore be processed serially. Here, the research has shown that: 1) subjects are not aware of most of the semantic information on the non-attended ear; 2) bilingual subjects are not aware that the messages are the same but in different languages (Treisman, 1964b); 3) subjects do not notice that the message on the non-attended channel is inverted speech (Cherry, 1953); and subjects are not aware that the message on the non-attended ear is a different language (Treisman, 1964b).

In summary, then, it appears that all kinds of physical information can be processed in parallel. Most semantic material is processed serially. It does appear, though, that a very limited amount of semantic information can be processed in parallel. There is still controversy between the Treisman (1960,

1969) and Deutsch and Deutsch (1963) models about how much semantic information does get through. One clear example of semantic information getting through is Moray's (1969) result that the person's name is almost always perceived on the non-attended ear. It appears that possibly those auditory stimuli that are habitually and consistently responded to whenever they occur (such as your name and the command "Fire") can be processed differently from the other semantic information.

It is quite possible that use of the shadowing task misses some of the more interesting questions. Shaffer and Hardwick (1969) point out many of the problems with the shadowing task. They suggest that shadowing is not an optimal or a natural mode of communication and that it would be better to find a task that looks at how subjects extract two or more messages under optimal conditions. Also, the loss of information in a shadowing task can be due to several things in addition to, or other than, a filtering bottleneck. One plausible possibility is that the loss of information could be due to the increased load. Subjects are required to do two tasks - speak while listening - and just the fact that the load is increased could cause the loss. Also, the loss of information could be due to interference between the recorded messages and the subject's own voice. Because of these reservations about the shadowing tasks, researchers have more recently been using a different kind of task, a monitoring task.

In a monitoring task, items (usually letters, digits, or other words) are presented paired in succession to the two ears at a certain presentation rate. The task is to find the target word in the distractors, as it occurs on either of the ears. Typically, single channel performance or the focused attention condition is compared with the two channel monitoring task. The deficit in performance due to channel size is the result of theoretical import.

Several studies have shown a deficit in performance when channel size is increased. Moray and O'Brien (1967) used a monitoring task. Subjects were required to monitor either one or two ears. They were to respond when any of the 100 target letters occurred in the 900 digit distractors. The presentation rate was 2 pairs/second. There was a significant reduction in d' when attention was divided between the ears than when attention was focused on one. They also found that both of a pair of targets are seldom detected if they occur simultaneously.

Shaffer and Hardwick (1969) also found a deficit when the channel size was increased. Subjects were required to monitor either one or two ears at a fast presentation rate (175 words/minute) or a slow presentation rate (145 words/minute). A deficit was found in both conditions. The hit rate for the slow presentation monitoring one ear was .948 (.001) (false alarms are in parentheses) and for monitoring two ears the hit rate was .684 (.001). For the fast presentation, the reduction was from .956 (.001) to .592 (.001) when channel size was increased. In this series of experiments they also included a condition where the speech was played backwards. In this condition the reduction was from .594 (.010) to .345 (.010) for the fast presentation and .48? (.012) to .256 (.017) for the slow presentation. Detection was much harder for these unfamiliar speech patterns, but a deficit still occurred.

Ninio and Kahneman (1974) found a deficit which was not quite as large as that found by the others. They presented subjects with trials composed of 10 pairs of words at 2 pairs/second for 40 experimental trials. In the divided attention task, subjects identified .779 (.030) of the targets while in the focused attention task subjects identified .964 (.022) of the targets. In summary, then, these three experiments show that when channel size is increased there will be a deficit in performance. All of these experiments used unpracticed subjects. Under these conditions it appears that subjects cannot successfully divide their attention and that auditory stimuli cannot be processed in parallel.

A few studies have shown that successful division of attention can occur under certain conditions. Treisman and Fearnley (1971) contend that items utilizing different analyzers can be processed in parallel. They compared reaction time (RT) to identify target words when monitoring two channels to a control condition where subjects had to monitor only one channel. Although there were significant differences between the two RT's, the differences were not as high as could be expected if the words were processed serially.

Pohlmann and Sorkin (1976) studied three-channel performance. Instead of words, their targets were pure tones. Subjects were required to detect the occurrence of a single tone in noise for the one channel task and in the three channel task, they were to detect one of three different frequency tones in noise. When analyzing d', they found that the decrement from the one channel to the three channel task was very small; only 29%. They concluded that pure tones can be processed in parallel.

Ostry, Moray, and Marks (1976) found no deficit when a divided attention task was compared to a focused attention task. Subjects were instructed to respond to letters that were embedded in digit distractors at a presentation rate of 2 pairs/second. In this experiment, subjects practiced for 10 days in one hour sessions. When d' for performance on the tenth day was compared to the comparable measurement in the focused attention condition that was run on the eleventh day, d' was 2.27 for both conditions. There was no deficit in performance when subjects were required to monitor two channels instead of one. There are several reasons why this experiment is different from the other monitoring experiments mentioned earlier. First, the subjects were well-practiced. In all the other experiments, subjects participated for one hour only. In this experiment, if the focused attention task was to be compared to the divided attention task of the first day, a deficit comparable to the other experiments would be found. Ostry, Moray, and Marks (1976) worry about the generalizability of the other studies that use unpracticed subjects claiming those results are probably unstable. Second, in this study a target was always a letter and distractors were always digits. Therefore, targets and distractors came from two mutually exclusive sets. This experiment shows that under the right conditions it is possible to monitor two channels with no deficit in performance.

A pattern of results seems to be emerging from these studies of focused and divided attention in audition. Studies show that most semantic information cannot be processed in parallel. The exceptions to that statement provide researchers with interesting situations. First, it had been found in the

focused attention studies that physical differences on the non-attended channels were noticeable. A similar finding was obtained by Pohlmann and Sorkin (1976) in a divided attention task. Pure tones, different from one another on a physical basis, could apparently be processed in parallel across three channels in this particular situation. Second, in some cases it was found that limited amounts of information were processed in parallel in focused attention tasks. Treisman and Fearnley (1971) argue that if words were from different verbal categories in a monitoring task, parallel processing could occur. Third, Ostry, Moray, and Marks (1976) found that practiced subjects perform differently from unpracticed subjects in a monitoring task. In this experiment, there was no deficit due to increased channel size. No such counterpart exists in the focused attention studies; the effects of practice were never investigated explicitly. The only possible similar finding to the Ostry et al. experiment in the focused attention literature is a subtle comparison of a previously mentioned result. Moray (1969) found in a shadowing task that a person's name could be identified on the non-attended channel. In some ways, the identification of a person's name is similar to the identification of the targets used in the Ostry et al. experiment: 1) people have had plenty of practice responding to their name; and 2) whenever a person's name is heard, the name is consistently responded to. In the Ostry, et al experiment, subjects had fairly extensive practice responding consistently to particular letters. Thus, studies in focused and divided attention yield results that are comparable in many ways. A situation that is especially interesting is those cases when it becomes possible to process information in parallel.

B. Visual Attention to a Single Event

Experiments in visual attention can be analyzed in much the same way as the auditory attention literature: those experiments that report serial processing and those that report parallel processing.

Sternberg (1966) found that subjects used a serial search in a visual attention search task. He gave subjects a set of characters (usually 1-6) that can be called the memory set. These characters were the targets. Then, a visual probe item appeared briefly on a screen. The probe item was either a member of the memory set or not. The reaction time in this yes-no task was analyzed. Sternberg found that it took on the average 40 msec/item to do the search and postulated a serial exhaustive model to account for these results.

Atkinson, Holmgren, and Juola (1969) found similar results in a slightly different experiment. They gave subjects a single memory set item. A display with several simultaneously occurring characters was presented. If the memory set item appeared in the display, subjects were instructed to respond positively and if the memory set item did not appear, they were instructed to respond negatively. Like Sternberg (1966), they found that the comparison rate was 40 msec/item. A serial self-terminating model was postulated to explain these results.

Several lines of research indicate that it might be possible to parallel process visual items. Gardner (1973), Shiffrin and Gardner (1972), and Shiffrin, Gardner, and Allmeyer (1973) ran a series of experiments addressing

this issue. They compared the simultaneous and sequential presentation of characters across four channels. In the simultaneous presentation, the four characters appeared all at once and subjects were required to find a certain target. In the sequential condition, the characters appeared in a known order one after the other and subjects were required to pick out the target. They found no difference between the ability to detect a target in the simultaneous display and the ability to detect a target in the sequential display. They argue that this constitutes evidence that it is possible to process characters in parallel. A possible problem with this line of research is that the task might not be difficult enough to find differences in the two conditions.

Similar to the auditory experiments, practice has been found to be an important effect in visual attention. Swanson and Briggs (1969), Simpson (1972), and Kristofferson (1972) looked at the effect of practice on performance. They found that the 40 msec/item slope mentioned in the previous studies was considerably flattened with practice. Like the Ostry, Moray, and Marks (1976) study, their memory set items were always targets and never distractors.

Keren (1976) makes a distinction between stimulus set items and response set items in visual attention following a similar distinction by Broadbent (1971) in audition. A stimulus set is characterized by some distinct and conspicuous physical properties that are inherent in the stimulus. A response set is characterized by the meaning it conveys. He found that stimulus set cues (such as location, color, size, and shape) could be processed in parallel. Response set cues are processed serially.

A picture very similar to that found in auditory attention has emerged in these visual attention experiments. Again, stimuli that differ according to physical properties can apparently be processed in parallel. Stimuli that do not differ in physical properties must usually be processed serially. The same exceptions to this statement have been found in visual attention studies. If subjects are well-practiced and if the memory set does not change, then it might be possible to process in parallel visual characters that do not necessarily differ physically.

C. Visual Attention to a Single Event:

The Schneider and Shiffrin Experiments

Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) reviewed and synthesized the research done in visual search and detection. Noticing that some experiments found items to be processed serially and some found parallel pocessing, they hypothesized that two kinds of processes, roughly similar to serial and parallel processing, could account for most of the data. They called these two control and automatic processing. Furthermore, they found that the development of automatic processing depended on the type of mapping of target to distractor. In the consistently mapped (CM) condition, if a target appears it is always a target and never a distractor throughout the experiment. With practice in a CM condition an automatic process to the targets will develop. If targets and distractors are in a varied mapping (VM) condition a target can be a target on one trial and a distractor on the

next. In VM conditions slow serial control processing will occur and no automatic processing will develop. This formulation is consistent with the findings in auditory and visual attention which were reviewed previously.

Several experiments were devised, especially those using a multiple-frame technique, to find quantitative and qualitative differences between automatic and control processing. A multiple-frame technique (Sperling, Budiansky, Spivak, and Johnson, 1971) is similar to the auditory detection experiments of Shaffer and Hardwick (1969) and Ostry, Moray, and Marks (1976). A string of characters, usually 20, occurs across four channels on a screen. The experimental trial variables that can be manipulated include: 1) the frame size - the number of characters other than masks that occur simultaneously; 2) the memory set size - the number of characters searched for; and 3) the frame time - the time from the onset of one frame to the onset of the next. The important variable that was manipulated was the type of mapping of target to distractor, either CM or VM.

Schneider and Shiffrin found quantitative and qualitative differences between control and automatic processing. Control processing was: 1) highly demanding of attentional capacity; 2) characterized by serial search; 3) easily established; 4) easily altered; 5) easily reversed; 6) easily suppressed; and 7) affected by the load requirements. On the other hand, automatic processing was: 1) not demanding of attentional capacity; 2) characterized by parallel search; 3) established with much difficulty; 4) not easily altered; 5) difficult to reverse; 6) difficult to suppress; and 7) virtually unaffected by load. Subjective experiences should also be noted. In an automatic process, the character that had been consistently mapped over a long period of time would tend to subjectively "pop out" of the display. Possibly, attention was automatically allocated to that stimulus.

In auditory attention, it is quite possible that subjects in the Ostry, Moray, and Marks (1976) experiment learned to automatically process the auditory stimuli. In their experiments targets and distractors were consistently mapped and subjects received extensive training. Their results showed the automatic processing characteristic of performance being unaffected by load. Under the right conditions it must therefore be possible to establish an automatic process to auditory stimuli - stimuli that change both temporally and spatially.

D. A Counterpart to Auditory Attention:

Studies in the Visual Mode

Nearly all attention researchers assume that there is basically no difference between auditory attention and visual attention (Broadbent, 1958; 1971; Hall and Swane, 1973; Fox, 1974; Keren, 1976; and Shiffrin and Schneider, 1977, to name just a few). Research in auditory attention uses stimuli that change temporally and spatially while research in visual attention has been characterized by responses to single, briefly presented events. One exception in visual attention does exist, though. Neisser and Becklen (1975) specifically tested the ability to focus attention to naturalistic events (events that change in time and space) and compared it to results found in

auditory attention.

Neisser and Becklen (1975) designed their experiment explicitly to be a counterpart to the selective listening experiments. They had two naturalistic episodes superimposed on a screen by the use of mirrors. One episode was the handgame where a player tries to strike another player's hand before the hand can be moved. The other episode, called the ballgame, had people pass a ball around a cirle. The subject's task was to count the number of hand slaps and/or the number of ball passes in a single, focused, or divided attention condition. The tapes could be presented at two speeds, either fast or slow, and the separate episodes could be presented either dichoptically or binocularly.

Neisser and Becklen (1975) found that generally, in a selective looking task such as this, it was relatively easy for subjects to selectively attend to one scene and ignore the other both in the dichoptic condition and the binocular condition. The hit rate for correct identification of the target events was very high, .96 to .98, and the false alarm rate was very low, essentially 0. Subjects generally found the divided attention task to be difficult; a deficit occurred when comparing the single episode performance to performance that required monitoring of both episodes. In the single episode, subjects had a hit rate of .98 to 1.00 and a false alarm rate of 0 to .03. Performance was much worse in the divided attention task where the hit rate was .61 to .79 and the false alarm rate was .11 to .15. The divided attention decrement occurred in both the dichoptic condition and the binocular condition; there was hardly any difference in the two.

Neisser and Becklen (1975) conclude that the continuous and coherent motion of the episodes makes it possible to selectively attend to one episode and ignore the other. Also, dichoptic presentation afforded no particular advantage to subjects over the binocular presentation. This is different from auditory experiments where messages presented dichoptically to the two ears can be selectively attended to more easily than messages that are mixed. Overall, they conclude that there are no separate global mechanisms of attention; rather subjects pick up one episode and don't pick up as much evidence about the other.

There are several problems with this study. First, dichoptic presentation in the visual mode is not similar to dichotic presentation in the auditory mode. In audition, different messages to different ears provides a very important cue, location, that helps in the selectivity process. In vision, dichoptic presentation affords no such location cue. Perhaps a better counterpart in vision would be to define different channels, as is traditional in visual attention research, by different spatial locations.

Another problem with this study is that naturalistic episodes are used. There are too many uncontrollable variables in naturalistic stimuli, and especially in the particular stimuli used by Neisser and Becklen. The crucial areas of the two episodes did not overlap very much; the handgame occurred in the fovea and the ballgame occurred in the periphery. The visual angle of the display was quite large, 12 degrees horizontally and 7 degrees vertically. It might be remembered that Broadbent (1958) was concerned about the differential aspects that the periphery plays in the perception of visual stimuli. This was one of the reasons he suggested that audition be used instead of vision in the

study of attention. Because of these problems, some of the conclusions made by Neisser and Becklen are tenuous. A method needs to be devised where stimuli can change temporally and spatially under exact conditions and experimenter control.

E. Apparent Motion

Neisser and Becklen (1975) hypothesized that cues of motion helped subjects in their attentive processes. If a visual display that changes temporally and spatially is to take advantage of such possible cues, optimal motion conditions must be considered in its design. Bell and Lappin (1973) found that motion is a sufficient cue for the discrimination of otherwise undifferentiated spatial patterns. It is also possible that motion, instead of individual events, could be a cue for the detection and identification of sequences of events that occur over several channels. Therefore, in doing research such as this, an investigator must be aware of the possible role played by apparent motion in visual attention.

The study of apparent motion has a long history of psychological research. Wertheimer (1912; but see Koffka, 1931, and Boring, 1942) got Gestalt psychology moving, so to speak, with his work on apparent motion. Because much of the research was done in the early part of the century, introspective techniques were used. In some of the recent studies, more sophisticated rating scales are usually used. Some work, such as Lappin, Bell, Harm, and Kottas (1975), has been done using forced-choice responses although the questions examined by these investigators are a bit different from those of the more traditional researchers.

The goal of the early research was to find the conditions for the occurrence of optimal motion. Graham (1965) summarized the variables that have been manipulated in this examination: 1) the length of pause between the two stimuli; 2) the duration of the first stimulus; 3) the duration of the second stimulus; 4) the luminances of the two stimuli; 5) the spatial interval between the two; 6) the shapes and sizes of the two stimuli; 7) the wavelength distributions of the two; and 8) the conditions of instruction. Many of the results of the early research and the relationships between the variables are summarized in Korte's Laws (1915; see Graham, 1965, and Boring, 1942). Several of these variables will be of concern in the construction of the trials for the following series of experiments. Of importance will be the length of pause between the two stimuli, the stimulus durations, and the spatial interval between the two.

Several kinds of apparent motion have been identified, investigated, and classified. Beta movement is the kind that is most often examined. A typical study of this phenomenon uses points of light, lines, or simple geometrical figures. Subjects are given a tachistoscopic presentation of one figure in one position and then, after a certain time period, another quick presentation of the figure occurs displaced by a certain distance. Under the right conditions, the figure appears to move from one position to the next. Much of the work in the field has been designed to find the conditions for beta movement, or the conditions for optimal motion.

Wertheimer (1912) tried to find the right conditions for optimal movement. With a tachistoscope he presented various kinds of objects - lines, curves, or figures - across a single, discrete displacement. By varying the inter-stimulus interval (ISI), the subjective experiences changed drastically. At an ISI of about 30 msec, the perception was one of simultaneity, the stimuli appeared togeher. At a longer ISI of 200 msec, the two stimuli appeared to succeed one another, the stimuli were seen as separate and distinct. However, at ISI's between 60 and 200 msec, various degrees of motion occurred and the two objects are seen as the displacement of one stimulus across the screen. Wertheimer concluded that optimal movement occurred with an ISI of 60 msec.

Wertheimer's (1912) conclusions on the optimal conditions for beta movement are no longer held. Wertheimer manipulated only the interval between the stimuli. Later work indicated that several other variables were important to the perception of apparent motion. A variable ignored by Wertheimer, the stimulus onset asynchrony (SOA), has subsequently been found to be very important in the establishment of optimal motion.

Kahneman (Kahneman, 1967; Kahneman and Wolman, 1970) argues that the quality of apparent motion depends only on the interval between the visual responses to the two stimuli which he terms the inter-response interval (IRI). The IRI is related somewhat to the SOA but is completely independent of the stimulus duration. Thus, for short stimulus durations, the visual reponse persists after the offset of the first stimulus so that the ISI is positive. For long stimulus durations, ISI should be 0 and it is even possible that the ISI will be negative. Kahneman (1970) sums up the research by stating two general rules: 1) for stimulus durations shorter than 100 msec, optimal motion occurs when the stimulus onsets differ by about 120 msec; and 2) for stimulus durations longer than 100 msec, optimal motion occurs when the second stimulus begins at the termination of the first stimulus.

The distance between the stimuli is also an important consideration in finding the conditions of optimal motion. Two of Korte's Laws (1915) directly address the issue. First, as the distance between the stimuli is increased, optimal motion can occur with an increase in the luminances. Second, as the distance increases, the ISI must also increase to maintain optimal motion. There appears to be a limit on how large the separation of stimuli can be. DeSilva (1926) found that optimal motion was perceived only if the displacement was no more than two degrees of visual angle.

Most research on apparent motion, as mentioned previously, has studied beta movement - the occurrence of two stimuli. Greenspon (1969) examined three-stimulus displays with no loss of the phenomenon of apparent motion. He argues that optimal motion in a three-stimulus display can be found by finding the conditions for optimal motion between stimuli one and two and finding the conditions of optimal motion for stimuli two and three. A three-stimulus display gave equally good movement when compared to a two-stimulus display. More recent research in apparent motion has been concerned with the metacontrast effect. The metacontrast effect is apparently a type of backwards masking. In a three-object display, the first stimulus appears and then is flanked by two other stimuli. Subjectively, the center stimulus usually becomes dim or completely invisible under conditions similar to those that were identified for

the occurrence of optimal motion. Because the conditions for optimal apparent motion and the metacontrast effect are the same, much speculation about the relationships between the two has been made. It seems to be generally accepted that the metacontrast effect is a kind of impossible motion (Kahneman, 1967). Because the center stimulus cannot move in two directions at once, an impossible motion, the center stimulus becomes dim or invisible. However, both Fehrer and Raab (1962) and Schiller and Smith (1966) dispute the claim of a completely suppressed first stimulus. When reaction time (RT) to the first stimulus under a metacontrast effect was compared to RT when the first stimulus was clearly visible, there was no difference between the two measurements. Apparently, the first stimulus is not completely suppressed. Besides this conclusion, the studies also point out the incompatibility between the introspective reports of the effect and the more objective RT dependent variable measurement.

Mayzner and his associates (Bushbaum and Mayzner, 1969; Mayzner, Tresselt, and Cohen, 1966) have studied a similar phenomenon to the metacontrast effect which they call sequential blanking. Mayzner, Tresselt, and Cohen (1966) presented subjects with five and ten letter sequences across the screen. The sequence of letters could be presented in a regular order, from one side to the next, or in an irregular order where the progression jumps around. As an example of an irregular order, CHAIR could be presented in the following sequence: 1) I; 2) H; 3) R; 4) A; and 5) C. They found that with an ISI of 50 to 100 msec the elements in the regular order displays were perceived with a strong and rapid flow of movement from left to right or right to left. However, at this ISI for the irregular order display, the first and second items in terms of order of appearance would disappear from the display. This effect did not occur when the ISI was increased to 800 msec. At an ISI of two to eight msec, all elements for both kinds of displays were perceived clearly as occurring simultaneously.

Bushbaum and Mayzner (1969) did a similar experiment using vertical lines. They found that if the lines occurred in an irregular order at an ISI of 20 msec, and all the lines were the same size, again the first and second lines in terms of occurrence were not perceived. However, in this study they also manipulated the size of the first and second occurring lines. They found that as the line length approached the lengths of the other three lines, detection went down. They hypothesized that lateral inhibition in the perceptual system could account for the results.

Interesting research on time and space relationships for visual patterns has been done by Lappin and his associates (Lappin and Bell, 1972; Bell and Lappin, 1973; Lappin, Bell, Kottas, and Harm, 1975; and Lappin and Bell, 1976). Lappin and Bell (1972; 1976) and Bell and Lappin (1973) used random dot patterns in their study of motion instead of the usual two-stimulus displays. They argued that the perception of motion could be based on a logical inference from spatial and temporal characteristics and not necessarily the particular motion. The salient cues provided by the simple figures in a two-stimulus display were removed by use of the complex random dot pattern. The subjects' task was to decide in which of four directions the spatial displacement had occurred between two successively presented random dot patterns. Lappin and Bell (1972) found that discrimination of the direction of movement fell to chance levels when the ISI was increased to 30 msec. Lappin and Bell (1976)

found that the exposure duration of the displays did not affect discrimination and that discrimination decreased as the spatial displacement increased. Many of the characteristics and relationships between time and space found here are different from that research using simple two-stimulus displays. The important thing is that to do the task with the random dot pattern displays, motion must be perceived instead of merely a spatial displacement. Therefore, under the right conditions, motion is a sufficient cue for the discrimination of otherwise undifferentiated spatial patterns.

Lappin, Bell, Harm, and Kottas (1975) investigated discrimination of a particular parameter, velocity, that must be described both temporally and spatially. The subject was to identify which of two alternative stimuli appeared on each trial. On different trials, the discrimination could be made according to distance, duration, or both distance and duration. The stimuli were either continuously moving dots of light or two flashes of light in good apparent motion and bad apparent motion. They found that the discrimination of the different-velocity stimuli (those differing in both distance and duration) was too accurate to be attributed to only discrimination of distance or duration alone. The higher discrimination of the stimuli that differed in both distance and duration ocurred only in the continuous motion and good apparent motion conditions. They conclude that time and space are perceptually related.

Therefore, in conclusion, the introspective and rating studies on apparent motion can be used to design the display under optimal motion conditions. Several of the results are useful in that design: 1) the stimuli should have durations of 100 msec with an ISI of 0; 2) the motion should not subtend more than two degrees of visual angle; 3) three-stimulus displays can be used; and 4) the stimuli can be lights, lines or simple geometrical figures. Along with Neisser and Becklen's (1975) suggestion that motion can be a cue in the attentive processes, the results and conclusions of Lappin and his associates suggest that motion can be an effective cue in discrimination and detection type tasks.

III. Display Characteristics and Classification

A. Display Characteristics

A sequence of events in this series of experiments was defined as three rapidly occurring line segments. Sequences could occur simultaneously across four channels specified by spatial location. Eriksen and Eriksen (1974) found that confusions of targets with distractors occurred if characters were not separated by at least one degree of visual angle. Thus, the different channels in the displays in this series of experiments were always separated by at least one degree to insure that lateral masking does not occur.

The experiments were computer controlled by a PDP 11/34 digital computer. Displays appeared on a Tektronix 604 or 620 cathode-ray tube scope which were equipped with rapidly decaying phosphor (P-31) with a refresh rate of 10 msec. The scope consisted of a 1024 x 1024 unit matrix such that each cell in the matrix could be individually controlled. The line segments for each sequence would all occur within a 60 x 60 unit matrix at six orientations in either six

or four positions per orientation. The orientations formed either 0, 30, 60, 90, 120, or 150 degree angles with the base line. The horizontal and vertical line segments could occur in six positions emanating from all four corners and from each side in the middle of the matrix. The other four orientations could occur in each of the four corners of the 60 x 60 unit matrix. Altogether there were 28 different line segments. Each line segment was 48 units long and subtended about .58 degrees of visual angle.

B. Classification Study

The choice of stimuli sequences offer practical as well as theoretical problems. If all possible sequences were generated from the 28 possible lines without replacement then there would exist 19,656 sequences to choose from. Which ones should be chosen? Similar studies in our lab using letters revealed that item effects are extremely important in trying to match the letters in difficulty and thus be able to interpret the results. The choice of stimulus sequences should not be arbitrary.

In auditory attention, researchers found that physical properties, such as pitch and loudness, helped to identify the messages. Do correlates to the auditory attention physical items exist in the visual attention study of sequences that change in time and space? If so, what are they? Several variables can be examined in this regard: 1) the number of direction movements; 2) the spatial separation from one event to the next; 3) the angle one line forms with the next; and 4) the discrepancy between the top (left) and bottom (right) of successive lines. One, or several combinations of these physical attributes, could be determinants of the ability to attend and select a target sequence from distractor sequences in a visual monitoring task.

As a further theoretical question, it is possible that a metacontrast effect will occur in the sequences. It could be possible that the first line segment will be dim, or not perceived at all. Recall that Bushbaum and Mayzner (1969) examined sequential blanking. They found that the first lines that appeared on the screen were not perceived by the subjects. It is possible that with some of the sequences, the first line segment will not be perceived or will be dim. In this case, identification of a target sequence will be completely determined by the second and third lines.

To try to settle some of these practical and theoretical questions, the problem is initially one of finding a suitable method of classification of visual stimuli. Once the sequences are classified and a diverse set has been devised, they can be used in a visual attention monitoring task where the criterion variable of per cent correct identification can be used in the analysis. Then a multiple regression technique can be used to analyze which of the variables - angle, distance, or discrepancy - account for most of the variance in trying to predict the criterion. Also, it can be determined which one of the gaps, the gap between the first two lines or the gap between the second two lines, accounts for more of the variance. With caution, possible causal relationships can be hypothesized using this technique.

1. The initial method of classification

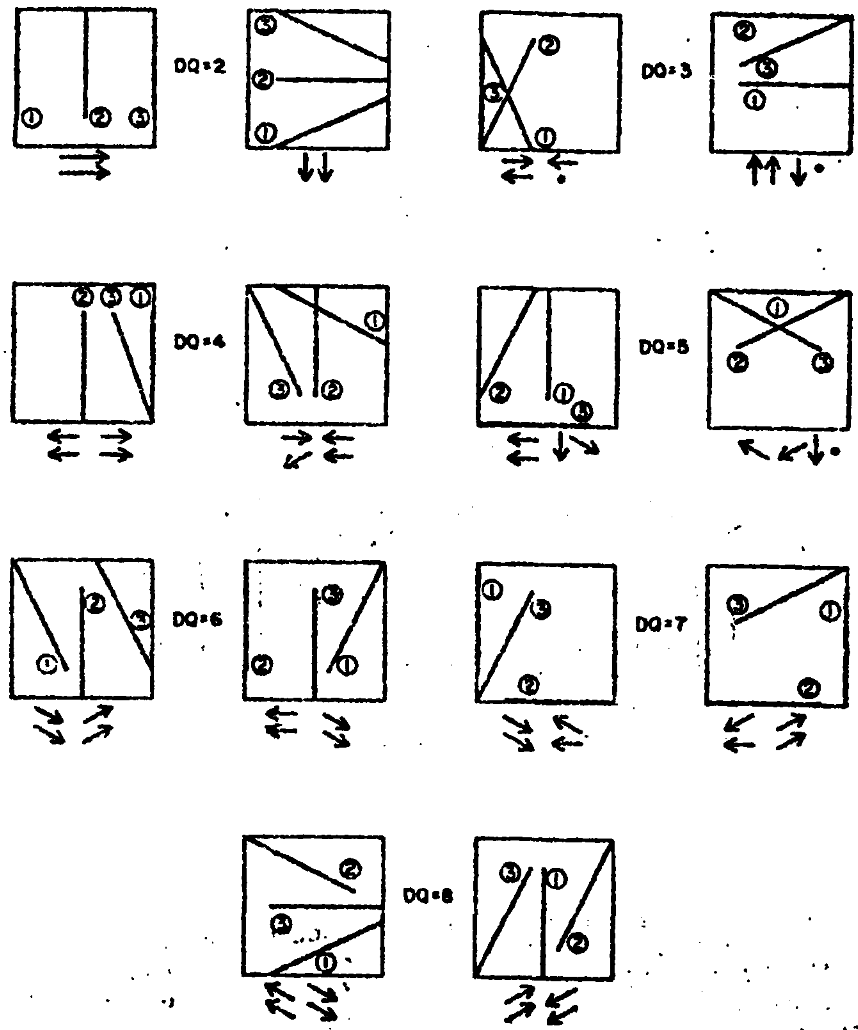


Figure 1. Examples of the classification of sequences according to the direction quotient (DQ). The arrows underneath represent the movement of each end of the line. The numbers represent the order of appearance of the lines.

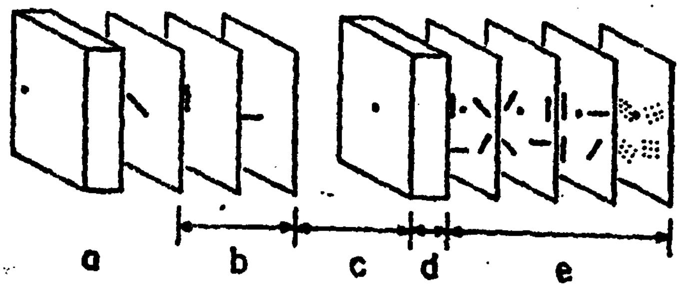


Figure 2. An example of a single sequence experiment: (a: the focus dot for the orientation target sequence; b: the presentation of the orientation target sequence; c: a one second pause; d: the beginning of the experimental trial with a focus dot; e: the trial display of four sequences followed by random dot masks. The target sequence appears in the upper right position.)

Restle (1979) used a method to classify circular motion. Some kinds of circular motion are ambiguous; the same successive dot configuration can be perceived to move in different motions. Restle (1979) defined the information load to be the number of parameters needed to define a motion. When the motion was ambiguous, and thus could be described by two or more different information loads, he found that subjects tended to perceive the motion according to that which could be described by the least number of parameters. Although the question posed by Restle (1979) and those to be investigated by this experiment are different, the Restle method does offer an initial method of classification that could be useful in devising a diverse sequence set.

Sequences for this, and the other experiments in this series, were randomly generated from the 28 line segments mentioned previously. Each of the 28 lines was assigned a number. A sequence of lines was generated by randomly choosing, without replacement, three of the numbers. Several sequences were generated.

The sequences were initially classified according to the number of direction movements within a sequence. At each end of a line segment, a directed arrow could be imagined. The arrow's direction pointed to the corresponding end of the succeeding line segment. Thus, for each sequence, there could be four directed arrows (one for each end of the line segment and two gaps between the three segments). Each arrow was then broken down into its vertical and horizontal components. As an example, an arrow that pointed downward to the right at a 45 degree angle would be broken up into a horizontal arrow pointed to the right and a vertical arrow pointed down. As a classification scheme, the number of direction movements was counted for the arrows at the ends of a line segment. This number will be referred to as the direction quotient (DQ). If no change of direction was reported from one arrow to the next, the DQ would not be incremented. See figure 1 for examples. The DQ could range from 2 through 8.

The DQ for each of the randomly generated sequences was determined. If DQ's of different values were possible for one sequence, the minimum was always chosen. For this experiment, 35 sequences were used. The first five sequences from the random sequence list for each of the seven DQ numbers were used as the experimental sequences. The number of possible sequences with a DQ equal to 2 is exceedingly small and none were generated randomly. In this case, all the possible sequences with a DQ of 2 were found and five were randomly chosen from this list.

2. Subjects

Seven University of Illinois undergraduates (six male) participated as partial fulfillment of a requirement in an introductory psychology course. All were right-handed and had normal or corrected-to-normal vision.

3. Procedure

The basic paradigm is illustrated in figure 2. Each trial consisted of the following events: 1) a focus dot signifying where on the screen the orientation target sequence would appear; 2) the target sequence of the three line segments; 3) a pause; 4) a focus dot in the middle of the screen; 5) a series

of four sequences appearing across four separate channels simultaneously; and 6) the subject response.

The subject's task was to identify the target sequence in the four sequences of the trial display. The target sequence always appeared in one and only one of the four positions. The subject responded by pushing, with the right index finger, one of four buttons on a response box that corresponded to the correct position on the screen in which the target appeared. As an example, if the target appeared in the upper right position, the subject would push the upper right button.

The 60 x 60 unit matrix for the orientation target sequence was centrally positioned to the left of the edge of the four 60 x 60 unit matrices of the trial display at a visual angle of 1.55 degrees. The total trial display subtended 3.95 degrees of visual angle with each 60 x 60 unit matrix subtending .86 degree of visual angle. Each matrix was separated from the other by 2.52 degrees of visual angle.

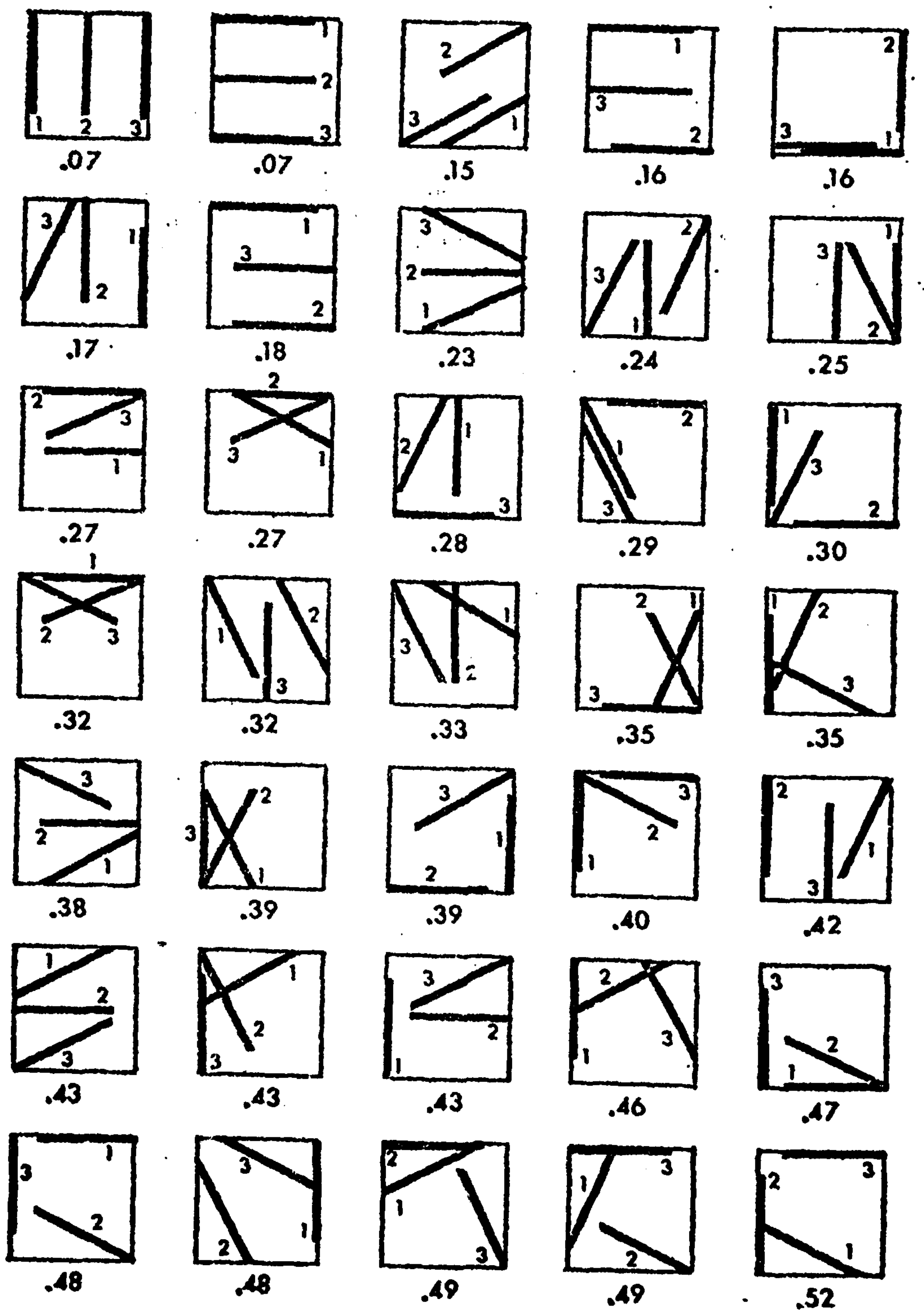
The appearance of the focus dot for the orientation target sequence was signalled by a 50 msec tone burst. After the 500 msec focus dot, the orientation target sequence appeared with a stimulus duration of 100 msec and an ISI of 0. There was a one second pause and then two 50 msec tone bursts signalled that the trial display would be appearing presently. Another 500 msec focus dot appeared in the middle of the screen and then the four trial sequences appeared to all four sides of the focus dot. Again, the stimulus duration was 100 msec with an ISI of 0. The subjects had four seconds to respond. If the subject made an incorrect response or no response at all, a 500 msec error tone occurred over the subject's headset. Subjects were instructed to make their best guess even if they did not see the target sequence. If a correct response was made, no feedback was given. In this particular experiment, the random dot masks in figure 2 at the end of the trial display did not occur. The masks were added for Experiment 1 and all succeeding experiments. There was a two second pause between trials. If the subject wanted to rest, the onset of the orientation target sequence could be delayed for 500 msec, as many times as desired, by pushing a button with the left index finger.

A block consisted of 70 trials; sequences from each of the seven DQ numbered groups were chosen randomly 10 times. Distractors were chosen ramdomly on each trial from any of the DQ groups other than the one that included the target sequence. Subjects participated an hour at a time for a total of two hours.

4. Results and Discussion

The 35 sequences are rank ordered with the error rate appearing underneath each sequence in figure 3. The average error rate for each of the DQ groups is presented in table 1. As can be seen, error rate is not an increasing function of the DQ number. It does appear that sequences in the DQ 2 group were easier to identify than the others. Upon an analysis of the individual sequences in that group, most of the low error rate could be accounted for by two of the five sequences. For these two sequences, the lines were all equally spaced and at the same orientation. These lines represented "good" motion. The error rates

Figure 3. The 35 sequences used in the classification study. The numbers 1-3 signify the order of presentation of the lines. The number under each sequence is its error rate.


.07 .07 .15 .16 .16
.17 .18 .23 .24 .25
.27 .27 .28 .29 .30
.32 .32 .33 .35 .35
.38 .39 .39 .40 .42
.43 .43 .43 .46 .47
.48 .48 .49 .49 .52

DQ	2	3	4	5	6	7	8
Errors	.214	.376	.328	.374	.310	.326	.356

Table 1. The error rate for the six DQ classification groups.

for both were quite low: .07. It appears, then, that the number of direction movements, as formulated here, makes very little difference in the ability to identify sequences, except when "good" motion occurs. However, "good" motion is confounded with the fact that all the lines are in the same orientation. Identification could be made on that basis instead. A large range of values was found for the 35 sequences. The easiest ones had an error rate of .07 and the hardest .52.

5. Multiple Regression Analysis

The following predictor variables were used for the multiple regression technique (see the Appendix for further clarification and an example).

1) Distance variables

The distance from both ends of the first line to both ends of the second line (called the distance across the first gap) was measured for a total of four distances altogether. The same measurements were made for the distances between the second line and the third line (called the distance across the second gap). Including both gaps, there were eight distances altogether. The average of the distances at each end of the line segments was found across both gaps. This number represented the distance that a point in the middle of the line would travel. This method yielded four numbers that were used in the regression analysis:

a) The minimum distance of the first gap;
b) The maximum distance of the first gap;
c) The minimum distance of the second gap; and
d) The maximum distance of the second gap.

2) Angle variables

To measure the angles of successive lines, the first line was used as a reference point. The acute angle of the extension, if necessary, of the two lines was used as the angle measurement. Thus, the following two angle variables were used in the regression analysis:

a) The angle between the first and second lines; and
b) The angle between the second and third lines.

3) Discrepancy measurements

Related, but not identical to, the angle measurements is a measurement that can be called the discrepancy. This measurement was found by taking the absolute value of the difference in distance of both ends of the line. This measurement yielded four numbers:

a) The discrepancy across the first gap using the minimum distances;
b) The discrepancy across the first gap using the maximum distances;
c) The discrepancy across the second gap using the minimum distances; and
d) The discrepancy across the second gap using the maximum distances.

4) The direction quotient as previously calculated.

In summary, 11 predictor variables were used in all. Four of the predictors were pure distance measurements, two were angle measurements, four were measurements that included both angle and distance, and the last was the direction of movement. In addition, five of the measurements were across the first gap and five were across the second gap in the three line sequence. Also, two of the measurements were minima and two were maxima. These 11 predictors should enable a detailed analysis of the data.

The multiple regression was performed by a matrix manipulation program developed by L. R. Tucker at the University of Illinois called FORMAL. The program was input with average error performance for the 35 sequences. There were 4800 observations in all for an average of 160 observations for each sequence.

The multiple correlation was .7699 and the squared multiple correlation was .5928. Table 2 contains the correlation matrix for the 11 predictors and criterion. In table 3, the means, standard deviations, regression weights, squared beta weights, and the additive constant are represented.

The relatively high squared multiple correlation signifies that these 11 predictors can account for a good deal of the variance of the error scores for each sequence. By examining the squared beta weights, the amount of variance accounted for by each component can be analyzed. Inspection of table 3 shows that all four of the distance predictors do not account for much of the variance. The angle measurements and discrepancies account for a good deal of the variance. Closer scrutiny of all these variables is warranted.

When the squared betas are rank ordered, two discrepancy measurements account for the highest amount of variance of all the components. The second gap variables, both the maximum which was .33 and the minimum which was .43, received the highest squared beta weights. Apparently, the sequences that are the hardest to identify are those where one end of the line doesn't change position very much but the other end of the line changes a great deal. This effect is the most prevalent across the second gap. It is also interesting to note that the discrepancies using the maximum and minimum distances both receive high squared betas. It should be remembered that maximum and minimum refer to the corresponding distances that were used to compute the discrepancies. The movement of the lines is ambiguous. Subjects can perceive the lines as moving across the minimum distance or they can be perceived moving across the maximum distance. However, possibly neither interpretation would be correct. The high squared betas for the dicrepancies determined from the minimum and maximum distances indicate that, possibly, distance is not used at all as a cue to resolve movement ambiguities. The low squared betas for all the distance measurements, ranging from .0015 to .0509, would seem to support that supposition.

The two pure angle variables are third and fifth in terms of the rank ordering. Two distance variables, minimum and maximum distances across the second gap, are fourth and sixth, respectively. The most prevalent finding, I

Table 2. The correlation matrix from the classification study. All 35 sequences are included in this analysis. The abbreviations used were: 1) min = minimum; 2) max = maximum; 3) dist = distance; 4) disc = discrepancy; 5) 1 = first gap; 6) 2 = second gap; and 7) DQ = direction suotient.

	angle 1	angle 2	min dist 1	min dist 2	max dist 1	max dist 2	min disc 1	min disc 2	max disc 1	max disc 2	DQ	crit
angle 1	1.000	.345	.357	.393	-.046	.308	.684	.302	.129	-.076	.273	.386
angle 2		1.000	-.044	.526	-.126	.145	.130	.708	-.049	.030	.234	.308
min dist 1			1.000	.310	.713	.429	.100	-.128	-.012	-.310	.504	-.165
min dist 2				1.000	.316	.551	.238	.195	-.079	.288	.563	.116
max dist 1					1.000	.400	-.216	-.199	-.279	-.327	.285	-.384
max dist 2						1.000	.082	-.143	-.258	.227	.350	-.071
min disc 1							1.000	.292	.149	.177	.301	.529
min disc 2								1.000	-.029	-.240	.033	.484
max disc 1									1.000	.188	.197	.113
max disc 2										1.000	.265	.297
DQ											1.000	.178
criterion												1.000

Variable	Mean	s.d.	Regression Weights	Beta Squared
angle 1	32	35	.00133	.1408
angle 2	31	33	-.00079	.0029
min dist 1	33	15	.00041	.0024
min dist 2	31	13	-.00207	.0509
max dist 1	56	12	-.00048	.0020
max dist 2	55	9	-.00213	.0248
min disc 1	22	20	.00024	.0015
min disc 2	24	19	.00420	.4320
max disc 1	13	12	-.00142	.0189
max disc 2	18	18	.00384	.3300
DQ	5	2.0	.00845	.0189
criterion	.33	.12	----	----

Additive Constant = .044

Table 3. The multiple regression measurements for the 11 predictors of the 35 sequences. The abbreviations used were: 1) min = minimum; 2) max = maximum; 3) dist = distance; 4) disc = discrepancy; 5) 1 = first gap; 6) 2 = second gap; and 7) DQ = direction quotient.

Variable	Mean	s.d.	Regression Weights	Beta Squared
angle 1	34	35	.00077	.0604
angle 2	33	33	-.00094	.0790
min dist 1	33	15	.00098	.0182
min dist 2	31	14	.00012	.0002
max dist 1	56	12	-.00263	.0824
max dist 2	55	9	-.00146	.0159
min disc 1	23	20	.00052	.0087
min disc 2	25	18	.00340	.3294
max disc 1	14	12	-.00168	.0331
max disc 2	19	18	.00249	.1767
DQ	5	2	.00069	.0001
criterion	.35	.11	----	----

Additive Constant = .072

Table 4. The multiple regression measurements for the 11 predictors of the 33 sequences. The abbreviations used were: 1) min = minimum; 2) max = maximum; 3) dist = distancel 4) disc = discrepancy; 5) 1 = first gap; 6) 2 = second gap; and 7) DQ = direction quotient.

believe, is that almost all of the first gap variables have low squared betas. In terms of the rank ordering, four of the five measurements across the first gap occupy the eighth through eleventh positions. The only exception is the angle measurement of stimulus 1 to stimulus 2 which is ranked third.

At this point, two results are important. First, the six angle measurements, excluding the discrepancy measurements across the first gap, generally account for more of the variance than the distance measurements. This implies that possibly subjects resolve the ambiguous motion by viewing the movement of the lines as occurring across the minimum angles. This conlusion is consistent with subjective reports and personal experience. Second, almost all of the second gap measurements account for a low amount of the variance. This implies that subjects discriminate the target sequence from the distractors by the last two lines that occur in the sequence and not the first two.

Most of the sequences analyzed were not "good" movement; orientation and distance varies within a sequence. Two of the sequences, the two on the left in the top of the first row of figure 3, are special; they represent "good" motion. Because the error rate for these two sequences was so low, the mutliple regression analysis could be biased to try to predict errors for those sequences. Because of this possibility, a further analysis was performed on the 33 sequences excluding those two representing "good" motion. The results of this analysis are presented in table 4. When this table is compared to table 3 there does not appear to be much difference between the two. Again, the two discrepancy measurements account for most of the variance and again the angle measurements are relatively high. However, there are two results in table 4 that are different from table 3. First, the DQ measurement for the second analysis accounts for the least amount of variance of all the predictors. In table 3, the DQ measurement is seventh in terms of rank ordering. This supports the earlier conclusion that the reason DQ 2 was identified better than the other six DQ classifications was because of the two sequences that represented "good" motion. Without those two sequences, hardly any of the variance is accounted for by the DQ measurement. Second, a reversal occurs in the distance measurements. In table 3, the measurements across the first gap accounts for very little of the variance. However, in table 4, the two first gap measurements account for more of the variance than the two second gap measurements and the maximum distance across gap 1 is now ranked third overall. The regression weight for this particular variable and the correlation between it and the criterion are both negative, however. In conclusion, this analysis on 33 sequences is very similar to the 35 sequence analysis in that the two discrepancies account for a great deal of the variance. The distance measurements are again low, except for the previously mentioned anomaly, and do not seem to be good predictors of performance. Also, the DQ measurement is almost useless as a predictor when "good" motion is not included.

Other possible sources of variance were not examined in this analysis. Some sequences could be easier to identify than the others on the basis of the design or pattern that the three line segments made. Some subjects reported that they tried to identify an "N" or a similar figure for some of the target sequences. Kolers (1964) argues that the mechanisms of apparent motion perception are closely related to pattern perception. The sum of the stimulus

durations in the present display, 300 msec, is exactly the time needed to perceive a pattern according to Kolers (1964). The determination of a good pattern and a bad pattern is not a variable that is easily quantifiable.

It should be remembered that multiple regression is a correlational technique. I have used in my conclusions such phrases as "the determinants of detection" and so forth. Such strong statements are not wholly justified in the absence of other experimental results. This study and analysis is meant only to be a first approximation to the hypothesized cognitive events in visual attention to sequences of events. The main purpose of this correlational study is to identify those variables that are important. A justified conclusion is that the angle of successive stimuli with each other is an important variable in the detection of sequences that change temporally and spatially. This variable should be manipulated and studied in controlled experiments. It is quite possible the sequences can be classified according to angle. Those sequences utilizing "good" motion (0 degree angle) should be the easiest to identify and attend to. Those sequences with large angles should be the hardest. It has been clearly established that the number of changes of direction does not provide the basis for a classification system according to difficulty of sequence detection. Also, it appears that the distance between the lines holds no promise as a possible classification variable either.

IV. Investigation of the Control Processing of Sequences of Events

Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) established that the type of mapping of target to distractor is important to the development or maintenance of the two kinds of processing. They showed that if a target is a target on some trials and a distractor on others (varied mapping (VM) situation), then control processing is maintained. Several characteristics of control processing were investigated. Among others, it is serial in nature and heavily dependent on load.

Most of the monitoring tasks in auditory attention have utilized a VM situation (Shaffer and Hardwick, 1969; Ninio and Kahneman, 1974). Most use unpracticed subjects and show deficits when the channel size was increased. The following series of experiments was run as a counterpart to the VM auditory attention experiments. Also, the possible use of movement cues in the control processing of sequences of events was investigated.

A. Experiment 1: Divided Attention in a VM Condition

This experiment examines divided attention to sequences of events. It is hypothesized that as the number of channels is increased, there will be a deficit in performance.

1. Stimuli

Sixteen sequences of intermediate difficulty were chosen from the 35 sequences used in the classification study. The probability of detection of the

stimuli from the previous experiment ranged from .65 to .80 with a mean hit rate of .73.

2. Subjects

Eight University of Illinois undergraduates (two male) participated as partial fulfillment of a requirement in an introductory psychology course. None had participated in the previous experiment. All were right-handed and had normal or corrected-to-normal vision.

3. Procedure

Several aspects of the previous experiment were changed. The size of the trial display was condensed so that the whole trial display of four 60 x 60 unit matrices now subtended 2.78 degrees of visual angle and the separation between matrices was 1.06 degree of visual angle. The orientation target sequence was now separated from the edge of the trial display by 2.22 degrees of visual angle.

The following changes were made in the trial procedure. To start a trial, subjects were now required to push a button with their left index finger. If a trial was not initiated in 30 seconds, it would start automatically. Thus, to delay a trial now up to 30 seconds, subjects would not push the button. The tone bursts signalling the beginning of the orientation target sequence and the trial display were deleted. Also, at the end of the trial display, random dot masks appeared in the four channels until a response was made. Otherwise, the trial itself was the same as that depicted in figure 2.

In this experiment and all succeeding experiments, extra feedback was given to the subjects. The percent of trials correct within a block of trials appeared on the display in the lower right corner of the screen after every response. When a trial was initiated, the number was removed from the screen. At the beginning of each block, all counters were initiated.

The independent variable of importance in this experiment was frame size (the number of channels that attention had to be divided among). The frame size was either 1, 2, or 4 and was a between block variable. The positions, a choice of four, of the sequences was chosen randomly before each trial. The remaining positions, in the 1 and 2 frame size conditions, were filled with masks. The target sequences were chosen randomly from the set of the 16 available sequences. On half the trials, the target appeared in the target display and on the remaining half, no target sequence appeared. Thus, the task was a two-choice button push. Subjects rested their index and middle fingers of their right hand on two buttons. Half of the subjects pushed the left button if a target appeared and the right button if no target appeared. The other half of the subjects had the opposite button assignment.

There were 64 trials per block. Subjects participated for three blocks in each condition for a total of 192 trials per condition per subject.

4. Results and Discussion

See figure 4 for the hits and false alarms. There is a large deficit when the number of channels is increased. Subjects had no trouble monitoring the one channel and identifying the target sequence. There was a large deficit in performance when the frame size was increased from 1 to 2. A smaller deficit occurred from 2 to 4. Thus, similar to results in auditory and visual attention research, a deficit in performance occurs as the load is increased. These results indicate that if the mapping is varied and unpracticed subjects are used, several channels of sequences which change in time and space cannot be monitored at once.

B. Experiment 2: Manipulation of the Stimulus Duration

Neisser and Becklen (1975) argued that subjects selectively attended to different episodes by following the movement cues of each separate episode. Although they used real motion, it is possible that motion cues might help subjects attend to the apparent motion of sequences of lines. Optimal motion occurs at an SOA of 100 msec and an ISI of 0 as established by Kahneman (Kahneman, 1967; Kahneman and Wolman, 1970). What happens when these optimal motion conditions are violated? Will possible motion cues be so strong that detection accuracy decreases even as the stimulus duration increases? If motion cues are used to help identify the sequence, then best performance should occur at the stimulus duration, 100 msec, that optimizes the occurrence of apparent motion.

1. Stimuli

The stimuli were the 16 stimulus sequences used in Experiment 1.

2. Subjects

Six University of Illinois undergraduates (two male) participated as partial fulfillment of a requirement in an introductory psychology course. None participated in previous experiments in this series. All were right-handed and had normal or corrected-to-normal vision.

3. Procedure

This experiment was very similar to Experiment 1 except for the following changes. As in the classification study, the target sequence always appeared in the trial display and the response was a four-choice position response. To repeat the example used earlier, if the target appeared in the upper right position, the subject would push the upper right button with the right index finger. The frame size was always four.

The independent variable of importance in this exeriment was stimulus duration. For the first five blocks of the experiment, the stimulus duration was 100 msec - optimal conditions for apparent movement. Then, for the next five blocks, the stimulus duration was manipulated as a between block variable. Stimulus durations of 50, 100, 150, 200, and 250 msec were presented to each subject in a random order. The stimulus duration of the orientation target sequence was the same as the stimulus duration of the trial display. The ISI

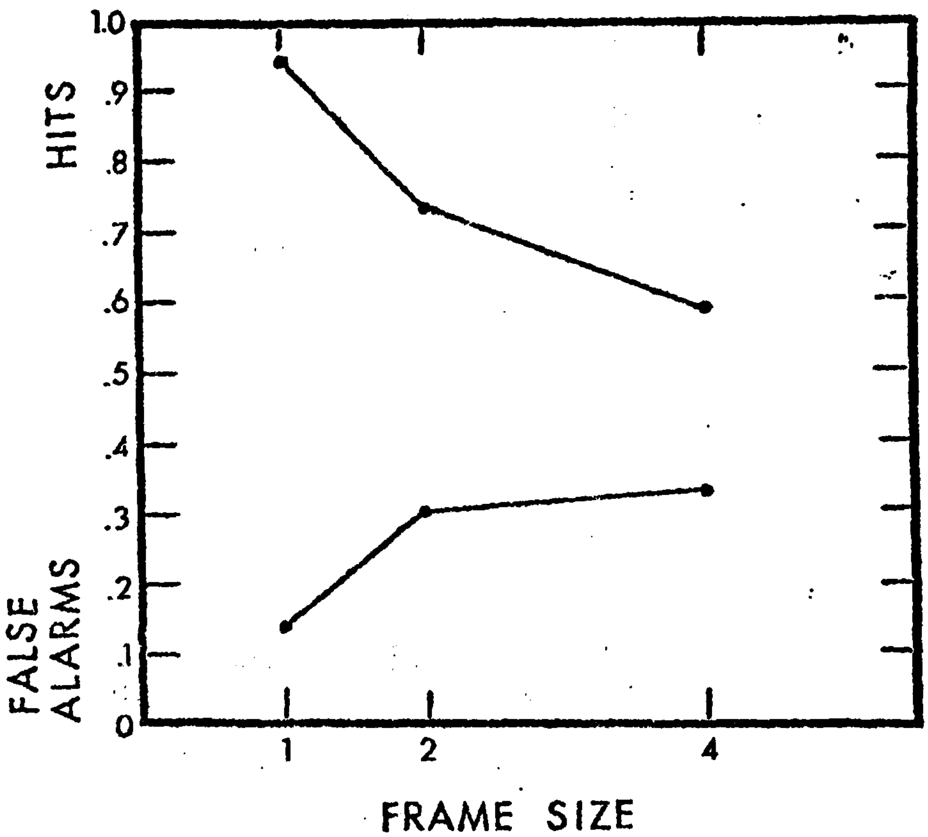


Figure 4. Data from Experiment 1: hits and false alarms as a function of frame size.

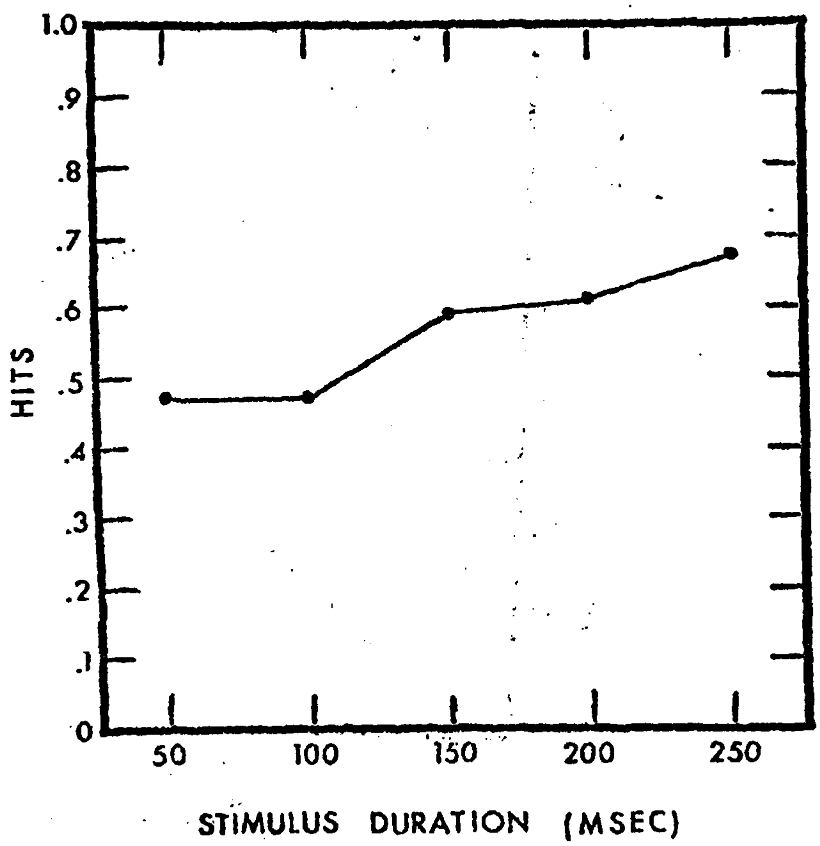


Figure 5. Data from Experiment 2: correct identification of the target sequence as a function of stimulus duration.

was always 0.

The sixteen sequence stimuli were divided into two sets with a mean detection rate of .73 for each set. Each block of trials contained one of the two sets of eight stimuli. Within a block, each stimulus appeared eight times for a total of 64 trials per block. Subjects participated in one hour sessions for a total of two hours.

4. Results and Discussion

See figure 5 for the detection accuracy of the sequences at the different stimulus durations. As the stimulus duration increases, so does the detection accuracy. Even after a short practice of five blocks at a stimulus duration of 100 msec, that duration is no better than any of the slower durations during the second part of the experiment.

There could be several reasons for these results. First, perhaps movement is not a good cue for the detection of the sequences. It must be remembered that these subjects are relatively unpracticed and because the individual lines change in orientation and spacing, "good" motion is not represented. Second, subjects could perhaps adopt a strategy of trying to identify individual lines. This strategy would appear to be a good one. Almost all the sequences can be distinguished by the occurrence of the third line in the sequence. Thus, as the stimulus duration increases, detection of this last line will be better and any advantage due to movement cues at the faster speeds would be overwhelmed by the individual line strategy at the slower speeds. Third, perhaps detection accuracy is not a fine enough measurement to find any evidence that movement cues aid the attentive processes.

If the sequences are seen as single segments and not as a coherent movement, it is not surprising that the longer stimulus durations should aid discrimination. Since the sequences are so different from each other, subjects have three chances to identify a line that will discriminate one from another. Perhaps sequences should be devised that are more similar to one another.

C. Experiment 3: Manipulation of Stimulus Duration of Similar Sequences

In this experiment, eight sequences were constructed that were very similar to each other. Four of the sequences always have the same line in each of the three positions. Thus, in a four channel display, if the sequences are chosen randomly, on the average two of the sequences will have the same last line. Sequences cannot be identified solely by the last line in this situation. Will motion cues become more salient? That is the question addressed by this experiment. Also, since the sequences will be so similar to each other, the discrimination should be difficult and detection accuracy should decrease.

1. Stimuli

Eight new stimulus sequences were constructed in the following way. Two sequences of about equal difficulty were chosen from the original 35 sequences used in the classification experiment. In that study, one of the sequences had

a hit rate of .62 and the other a hit rate of .59. They were the thirty-first and thirty-second sequences respectively in terms of difficulty. Each of the two sequences was broken up into its constituent line segments yielding six segments altogether. All possible combinations of these six line segments, keeping position constant, were constructed. This procedure yielded eight sequences altogether - the original two plus six new ones - such that each line segment could appear in half of the eight sequences. Thus, as an example, if the last line segment in one sequence was vertical in the lower right hand corner, three of the other sequences would have that same line segment in the last position.

2. Subjects

Twelve University of Illinois undergraduates (one male) participated as partial fulfillment of a requirement in an introductory psychology course. None had participated in any of the previous experiments. All were right-handed and had normal or corrected-to-normal vision.

3. Procedure

This experiment was very similar to Experiment 2. Again, for the first five blocks of the experiment, the stimulus duration was 100 msec. After this initial training, the stimulus duration was manipulated as a between block variable with times of 50, 100, 150, 200, and 250 msec. Subjects ran in two blocks at each of the five frame times for a total of 10 blocks and 128 trials per condition. The order of the variable stimulus duration blocks was randomized for each subject.

There was one other change from Experiment 2. In addition to the feedback given in the previous experiments, in this experiment an X marked the spot on the screen where the target sequence had appeared in the trial display if subjects made a mistake. The X remained on the screen for 500 msec.

4. Results and Discussion

Look at figure 6 for the detection rate. Notice that the characteristics of this data are a bit different from that found in Experiment 2. Here, a stimulus duration of 200 msec provides subjects with the easiest discrimination time. In Experiment 2, the easiest time was 250 msec. Also, detection accuracy is quite low here. Subjects could only identify 37% of the targets at the 100 msec time as compared to 57% of the targets in Experiment 2.

An exact comparison between Experiment 2 and this experiment cannot be made. Different sets of subjects were used, the subjects had more practice in this experiment, and more subjects were used. But, a definite break point at 200 msec does occur in the data, something not observed previously.

If the optimal motion does occur with a stimulus duration of 100 msec and an ISI of 0, then performance should be best at that duration if motion cues are used in identification. If motion cues are not used, performance should be best at the higher durations where the movement cues are not as prevalent. This was the case. If movement cues are not used, then subjects must try to identify the

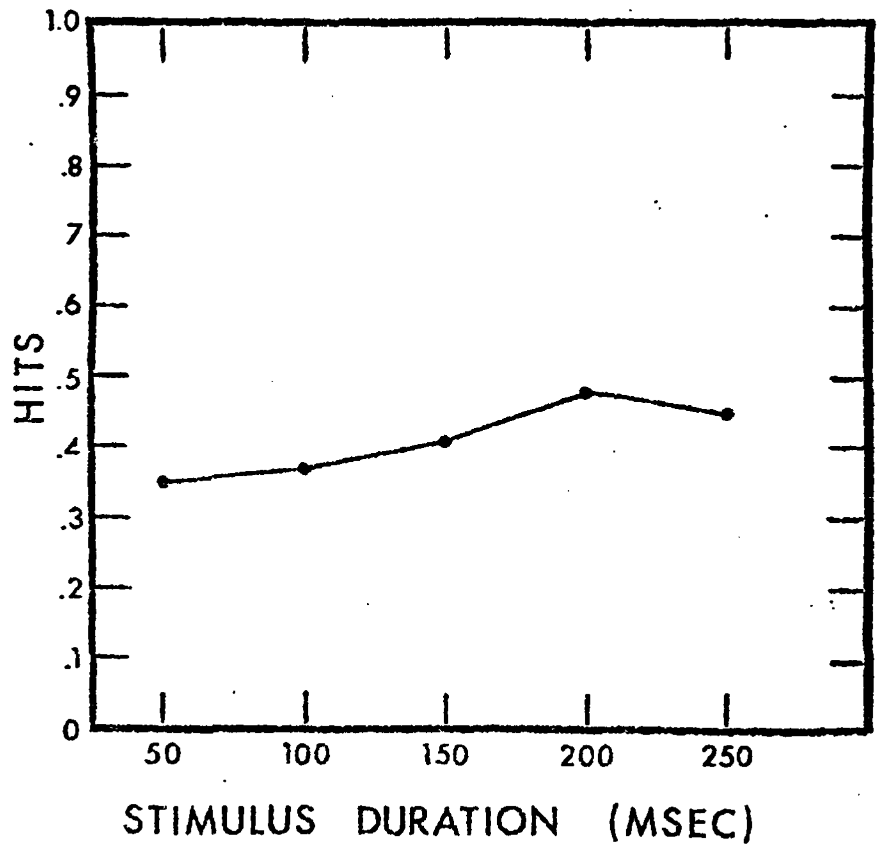


Figure 6. Data from Experiment 3: correct identification of the target sequence in a field of similar sequences as a function of stimulus duration.

sequences by identifying individual lines. At slower durations, subjects would have more time to identify the individual lines. The drop after the 200 msec duration could be due to a decay in the memory trace with time. The display stayed on for a total of 750 msec in the longest duration condition and only 300 msec in the 100 msec condition.

V. An Investigation of the Automatic Processing of Sequences of Events

The paradigm developed by Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) enabled an experimental investigation of the two kinds of processing, automatic and control. Because subjects were well-practiced, skilled visual processing could be assessed. The practiced subjects in the Ostry, Moray, and Marks (1976) auditory attention experiments also displayed similar skilled characteristics. Both sets of subjects, under the right conditions, could divide their attention across several channels with no deficit. Schneider and Shiffrin would attribute this to the ability of the subjects to automatically process the stimuli. The automatic processing of stimuli has been investigated in audition to stimuli that change temporally and spatially, and visually to single stimuli. Can subjects automatic process visual stimuli that change temporally and spatially? With this overall question in mind, several experiments were conducted.

A. Experiment 4: CM and VM Differences

The previous group of experiments did not look at the changes that occur with practice. Also, all of the subjects were in a VM condition. If the targets and distractors in one set of sequences are consistently mapped and in another set, the targets and distractors are in a varied mapping condition, then as Schneider and Shiffrin (1977) found, there should be quantitative differences between the two groups over time.

1. Stimuli

The 16 stimuli used in Experiments 1 and 2 were used in this experiment. They were divided into two sets, set A and set B, with each set having a mean hit rate of .73 from the classification study. Each subject was assigned one target sequence that would remain with him or her throughout the rest of the series of experiments. Four subjects were assigned targets from set A and four were assigned targets from set B. The target sequences were matched according to difficulty with the hit rate from the classification study ranging from .70 to .76.

In a consistent mapping (CM) procedure, distractors were always chosen from a set other than that which contained the particular subject's target sequence. As an example, if the first subject's target sequence was chosen from set A, the distractors would be chosen from set B. Thus, a target sequence was always a target and never a distractor. In a varied mapping (VM) procedure, distractors and targets were randomly chosen from the same set (e.g., in the VM conditions both the target and distractors come from set B). Thus, in this case, a target

could be a target on one trial and a distractor on the next trial.

2. Subjects

The subjects were eight University of Illinois undergraduates (four male). They were paid $3.00 an hour for their participation. None had participated in any of the previous experiments. All were right-handed and had normal or corrected-to-normal vision. These eight subjects participated throughout the remaining experiments.

3. Procedure

The procedure was identical to that of Experiment 2 except for the following changes. The independent variable of importance in this experiment was the type of mapping used - CM or VM. This independent variable was a between block variable. The order of presentation of the blocks was randomized within groups of two. A CM block in conjunction with a VM block will be termed a session. The stimulus duration at all times was 100 msec.

Each subject participated in 30 blocks of trials, 15 in each condition, over several days. Subjects 5 and 6 had to be continued for 3 and 5 more sessions, respectively, until they reached a criterion of 85% correct detection in either the CM or VM condition. The other subjects had already reached their criterion at or before the fifteenth session. All subjects, except 5 and 6, had 960 trials total in each condition. Subject 5 had 1344 trials and subject 6 had 1620 trials in each of the conditions.

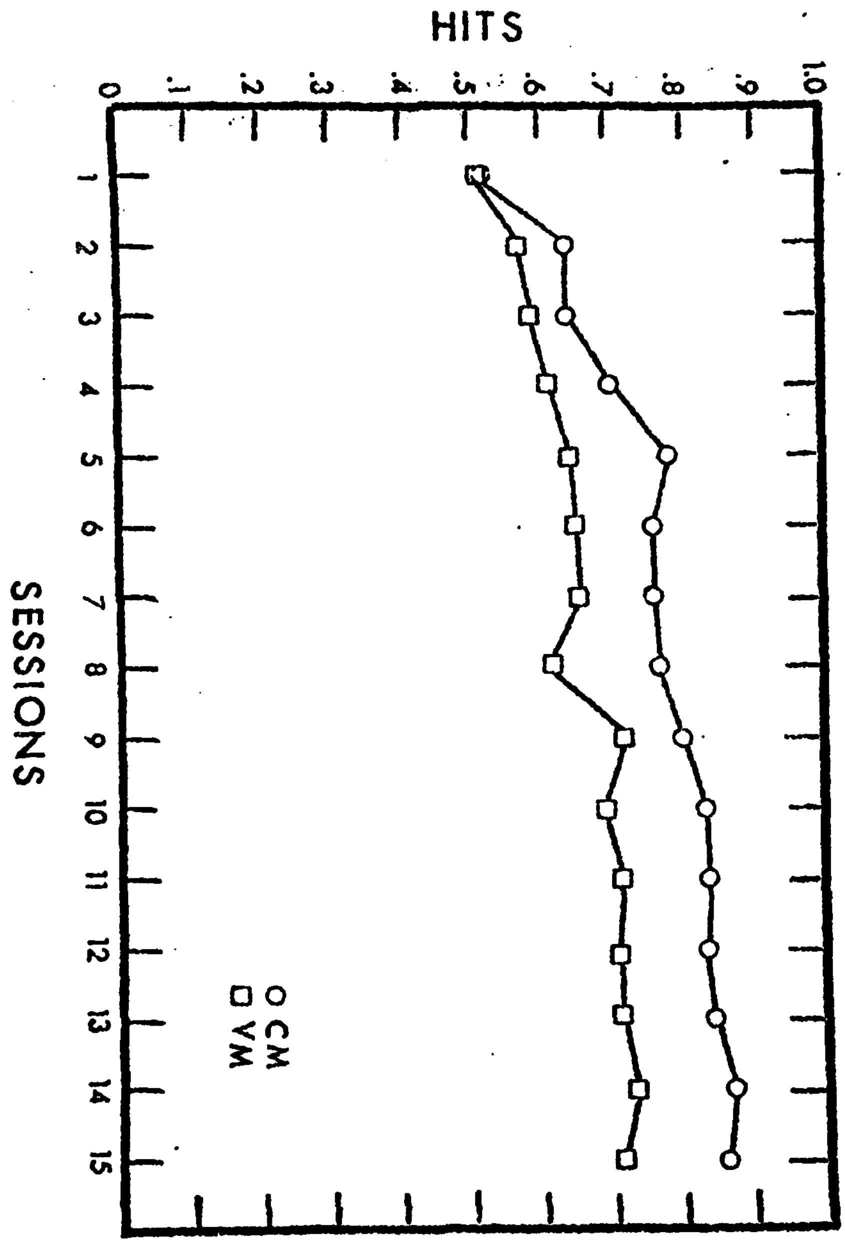
4. Results and Discussion

See figure 7 for the hit rate. As can be seen, there is no difference between the CM and VM conditions in the first session - the sequences had been matched in difficulty. Differences between the two groups develop by the second session and remain throughout. The VM group stayed within a tolerance range of plus or minus .02 within the last six sessions so it appears the function had asymptoted and continued practice would not improve performance. The CM performance had apparently leveled off also, though at a higher accuracy. The CM and VM differences were consistent across all eight subjects. All subjects showed the difference in their last session with differences ranging from .07 to .21.

Like Schneider and Shiffrin (1977), there were quantitative differences between the CM and VM groups. Whether the two groups of sequences are being processed differently, is a question that still needs to be answered. The quantitative differences exist; subjects have a harder time dividing their attention across four channels in the VM condition than in the CM condition. Continued practice would not raise the VM group to the level of performance achieved by the CM group. Qualitative differences between the two groups need to be found, though.

Like Ostry, Moray, and Marks (1976) performance can be high when monitoring two channels for the occurrence of a particular spatial and temporal pattern if subjects are practiced and the mapping is consistent. This is not exactly

Figure 7. Data from Experiment 4: correct identification of CM trained and VM trained sequences over 15 sessions.


HITS
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
SESSIONS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
○ CM
□ VM

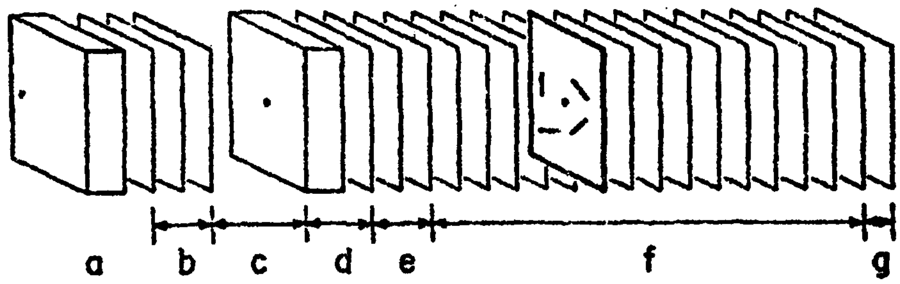


Figure 8. An example of a multiple sequence experiment: (a: the focus dot for the orientation target sequence; b: the presentation of the orientation target sequence; c: a one second pause; d: the beginning of the experimental trial with a focus dot; e: a sequential display of four sequences; f: the remaining five sequential displays, which, along with e constitutes the trial display; g: a frame of four random dot masks.)

similar to the auditory attention task in that only one spatial and temporal pattern occurs per trial in this situation. In auditory monitoring tasks, subjects are presented with several words - several spatial and temporal patterns - on one trial and are required to pick out the target word.

B. Experiment 5: A Multiple Sequence Procedure

In many of the experiments of Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) a multiple-frame procedure was used. This procedure was similar to the monitoring tasks used in auditory attention experiments. For these sequence experiments, a multiple sequence procedure can be devised. CM and VM differences should still exist if such a procedure is used.

1. Method

The same stimulus sequences as in the previous experiment were used.

A multiple sequence display was utilized in this experiment. See figure 8 for an illustration of the basic paradigm. A trial display in this case consisted of the four channels of now six sequences, following one another on each channel. Eighteen lines (six sequences of three lines each), then, would occur across a single channel. What was designated a trial display in the last experiment (the simultaneous occurrences of one sequence on each channel), will be termed a sequential display in this experiment. Thus, the whole trial display consisted of six sequential displays of 18 frames; each line had a stimulus duration of 100 msec.

One of the sequences ended with the same line segment that started a second sequence. Therefore, a stipulation was that these two stimulus sequences could not appear in succession. Otherwise, four different sequences were randomly chosen for the particular sequential display. The target sequence was randomly placed in sequential displays 2 through 5. The task, a four position button response, was the same as in Experiment 4.

Again, CM and VM blocks were randomized within groups of two. Subjects participated for a total of two sessions (four blocks). Thus, each subject had 128 trials of CM multiple sequences and 128 trials of VM multiple sequences.

3. Results and Discussion

The hit rate in the CM condition was .46 and in the VM condition it was .39. A one-tailed t-test, with 1536 observations per point, on the difference between the CM and VM groups yielded an approximate z-score of 3.924. This is a highly significant difference ($p < .001$).

Although the hit rate was relatively low, the CM and VM differences still remained in this multiple sequence task.

C. Experiment 6: The Effect of Load for CM and VM Sequences

If the CM sequences are automatically processed and the VM sequences are control processed, then the CM sequences should be processed in parallel, unaffected by load, while the VM sequences should be processed serially with an affect due to load. This hypothesis will be tested in the following experiment.

1. Method

The stimulus sequences used in the previous experiment were also used here.

A multiple sequence procedure, similar to Experiment 5 except for the following changes, was used. Subjects participated in ten sessions altogether. For the first five sessions, subjects monitored only one channel. The relevant channel was chosen from the four possible positions randomly before each trial. The first four sessions were used as practice. In the final five sessions, subjects were required to monitor two channels. The positions of the two channels were chosen randomly from the four possible positions before each trial. The first four sessions of this condition were also used as practice.

The task in this experiment was a two-choice yes-no button response similar to Experiment 1. The button assignment was counterbalanced across subjects. Each block contained 64 trials; 32 positive trials and 32 negative trials.

2. Results and Discussion

See figure 9 for the hits and false alarms for each condition. As can be seen, there is a noticeable interaction between the hits and false alarms for the two groups as the channel size increases. There is a slight drop in CM performance in hits and a slight increase in the false alarms as the frame size is doubled. However, in the VM condition, there is a huge drop in the hit rate and a large increase in false alarms as the channel size is increased. Both CM and VM performance in the single channel monitoring task is just about equivalent. Only with an increased load - doubling the channel size - do the differences between CM and VM sequences occur.

A slight deficit in performance can be expected in the CM sequences when the channel size is increased. Schneider and Shiffrin (1977) also found a slight deficit in CM performance as their frame size was increased from 1 to 4 in a multiple frame task. Eriksen and Hoffman (1972, 1973) showed that subjects could not eliminate noise item effects completely even if they knew in which position the target would occur. In the two channel condition, the movement of lines on the other channel is bound to have some kind of distracting effect.

Subjects were practiced for a long period prior to the collection of the data for two reasons. First, in this experiment subjects were required to respond differently. After more than 1500 trials of a four-choice position response from the previous experiment, here a two-choice yes-no response was required. Shiffrin and Schneider (1977) speculate that under some situations, an overt motor response to a button press can be learned. Thus, before stable performance can be assessed in this experiment, the overt motor response, if it exists, must be unlearned. Second, from the one experiment to the next, the target probability was reduced from 1.0 to .5. Colquhoun and Baddeley (1964) showed that target expectancy had differential effects on performance.

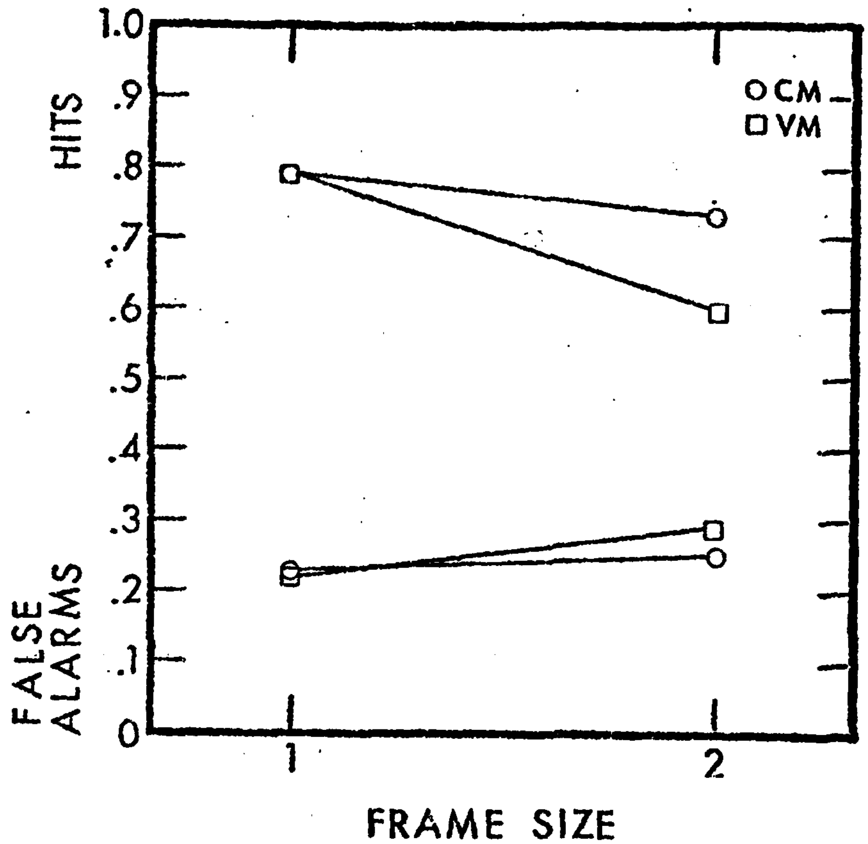


Figure 9. Data from Experiment 6: hits and false alarms of CM and VM sequences as a function of frame size.

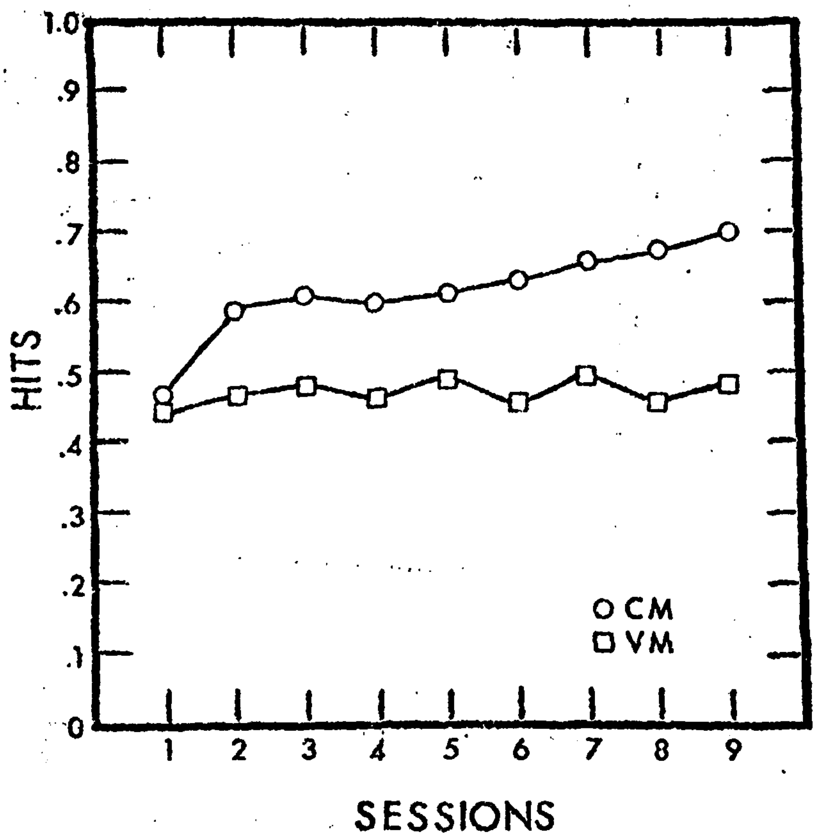


Figure 10. Data from Experiment 7: correct identification of CM and VM target sequences over nine sessions in a multiple sequence procedure.

Performance was not assessed until subjects had learned the particular contingencies of this experimental task.

In conclusion, this experiment showed that when the channel size doubled there was only a slight deficit in the identification of CM trained sequences and a huge drop in performance in the identification of VM trained sequences. This result, more so than the results of the previous experiments, suggests that two different kinds of processes are involved. The CM trained sequences can apparently be processed in parallel unaffected by load. The VM trained sequences are processed serially by a process affected by the load requirements. At this point, it appears that after sufficient practice, sequences of events can be automatically processed.

D. Experiment 7: A Modified Multiple Sequence Experiment

In Schneider and Shiffrin's (1977) multiple frame experiments each character has a definite beginning and a definite end. In an auditory monitoring task, the digits, letters, or words are separated from each other by gaps. Perhaps, as a counterpart to the multiple frame task and the monitoring task, the sequences in a mutliple sequence task should be separated from each other; the sequences should have a definite start and a definite end. The effects of practice in this modified multiple sequence experiment were examined.

1. Method

The stimuli were the same as those used in the previous experiments.

The procedure was exactly the same as that of Experiment 5 and the illustration of figure 8 except for the following changes. In this experiment each sequence was separated from the next sequence by a 100 msec random dot mask. In figure 8, then, after every three frames in the trial display, a frame of masks was inserted. Also, as in Experiment 3, an X marked the position where the target sequence appeared if the subject made a mistake.

Each subject participated in nine sessions (two blocks/session) for a total of 575 trials per subject for each CM and VM condition.

2. Results and Discussion

Look at figure 10 for the hit rate in the CM and VM conditions. The results are similar to those of Experiment 4. CM and VM performance started out fairly equal. Differences occurred at the second session and expanded throughout the experiment. It appears that the VM curve had asymptoted; CM performance was still improving when the experiment was terminated. As in Experiment 4, CM performance was superior to VM performance for all of the subjects.

The results from this experiment can be compared with Experiment 5 where a multiple sequence procedure was used but masks did not separate the sequences. After two sessions in Experiment 5, the hit rate was .46 and .39 for CM and VM sequences, respectively. In this experiment, the hit rate was .59 and .46 for CM and VM sequences in the second session. Separating sequences by masks

apparently made the task easier.

E. Experiment 8: Rotation of Sequences

Subjects at this point were extremely well-practiced in their task. It has been argued that these subjects are learning or have learned to automatically process the CM sequences of events. This automatic process is different from that established by Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) only by the nature of the task, not by the process itself. Whereas the Schneider and Shiffrin subjects learned to automatically process a single event, subjects in these experiments have possibly learned to automatically process a sequence of events where no single event defines the target. Subjects are responding to coherent and integrated relationships between the lines; a particular temporal and spatial pattern in the CM condition.

The tendency to respond to coherent relationships might not be as strong for the VM sequences. If subjects responded to a pattern, then on some trials that pattern would be a distractor and it would not be an advantageous strategy to have attention automatically directed to that particular pattern. Perhaps subjects in this situation would adopt a different strategy of trying to respond to separate events. Apparently, this was the strategy adopted by unpracticed subjects in the VM experiments, and so it must be a strategy that is easy to set up and disband. Responding to temporal and spatial patterns could take more effort to establish.

In this experiment, the relationships between the lines were kept constant while the single lines themselves were changed. This can be achieved by rotating the whole sequence. It is hypothesized that detection of the CM rotated sequences should still be better than that of the VM rotated sequences.

1. Stimuli

The same stimulus sequences as in the previous experiments were used. However, the 60 x 60 unit matrices which contain the sequences were rotated either 0, 90, 180, or 270 degrees. Both the target sequences and the test sequences were presented rotated.

2. Subjects

The same subjects were used.

3. Procedure

The display was a single sequence procedure similar to Experiment 4. An X marked the correct position of the target sequence if an error occurred. The four levels of rotation - 0, 90, 180, or 270 degrees - was a between block variable. The order of presentation of the blocks was randomized. Four blocks of one each of the four possible rotations was termed a session. Subjects participated for a total of three sessions.

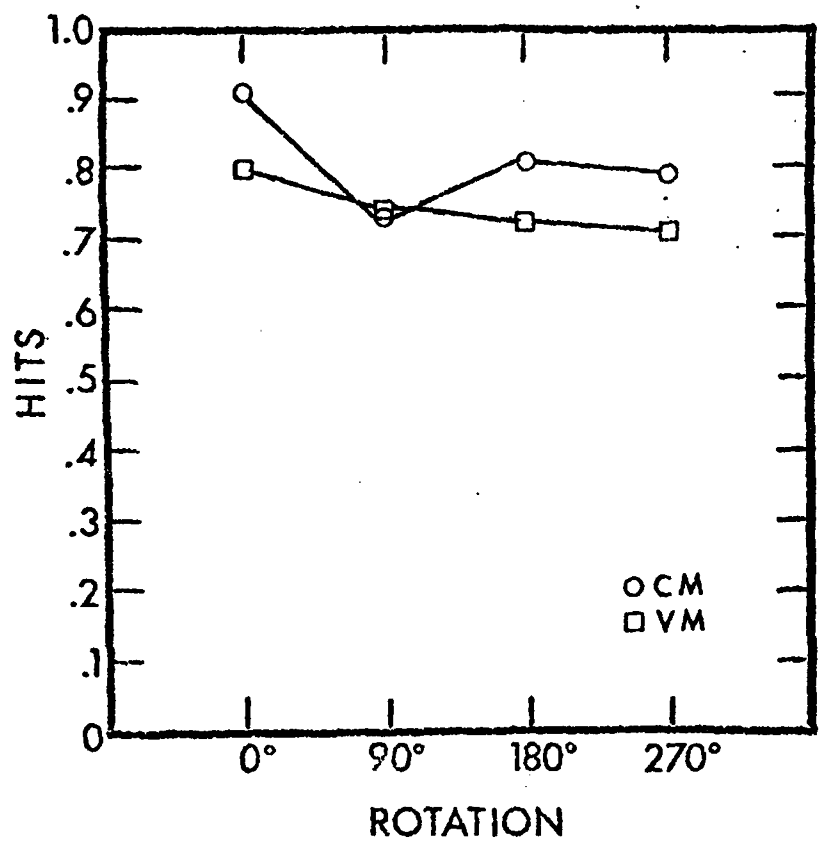


Figure 11. Data from Experiment 8: correct identification of CM and VM sequences as a function of degrees of rotation.

In this experiment, the mapping (either CM or VM) was a between trial variable. The CM rotated target sequence appeared as many times (eight) as each of the eight VM rotated sequences. A block contained 72 trials. For each subject in each rotation condition there were 24 observations for each of the nine possible targets.

4. Results and Discussion

See figure 11 for the detection rates. The eight VM rotated target sequences have been combined to form one point. Differences exist between CM and VM rotated sequences at three of the four rotations.

It was generally easier to identify the rotated sequences that were CM trained than those that were VM trained. The exception seemed to be the 90 degree rotation. No explanation can be offered why detection was not as high as the others; the lack of a difference seemed to be due to a drop in detection of the CM rotated sequence and not an increase in the VM rotated. The difference across the other rotations cannot be explained by practice effects. Each target sequence, CM rotated and VM rotated, occurred exactly the same number of times. There must have been differential familiarity with the relationships between the lines of the two groups. It has been hypothesized that the CM sequences are perceived as a coherent temporal and spatial pattern whereas VM sequences are perceived as separate lines. This experiment offers tentative support of that hypothesis.

F. Experiment 9: Manipulation of CM and VM Stimulus Durations

Subjects have been well-practiced at identifying sequences at a stimulus duration of 100 msec; a duration that should provide optimal movement characteristics. What will be the effect of making the duration shorter or longer? It was argued in Experiments 2 and 3 that the motion cues could possibly help the subjects identify the sequences. With unpracticed subjects, though, motion cues did not seem to play a very important role in the attentive process. However, the results of the last experiment suggest that subjects attend to the relationship between events more for CM than VM sequences. Because of these two considerations, motion cues might now play a bigger role in the attentive processes.

In this experiment, the stimulus duration is both shortened and lengthened. If motion cues play an important role in the identification of sequences, then detection should be highest when the stimulus duration is optimal for the perception of apparent motion. This effect should be most prevalent for the CM sequences. Since the VM sequences are not perceived as coherently, there should be an improvement in performance as the stimulus duration is increased.

1. Method

The stimulus sequences from the previous experiment were used.

The procedure was similar to that of Experiment 4 except for the following changes. Stimulus duration was manipulated as a between trial variable. Five stimulus durations were used: 30, 60, 100, 180, and 250 msec. Within a block, the 100 msec trials appeared eight times more often than each of the other stimulus durations. Each block contained 72 trials. Again, type of mapping was manipulated as a between block variable and was randomized within groups of two. A session was designated as a block of CM trials plus a block of VM trials. Subjects participated in a total of five sessions. Thus, for each subject in either the CM or VM conditions, there were 240 observations for the 100 msec stimulus duration and 30 observations for each of the other four.

2. Results and Discussion

See figure 12 for the detection rate across the five stimulus durations. CM and VM differences exist across all durations. In the CM condition, the highest detection rate, .92, occurs at the 100 msec duration. For the VM condition, the highest detection rate, .81, occurs at the longest duration, 250 msec.

As hypothesized, the best performance occurred in the CM condition at that stimulus duration that optimizes apparent motion. It seemed to be a fairly robust effect across subjects; 100 msec was the best time for five of the eight subjects. For two of the subjects, a longer duration had a higher detection rate within one or two percentage points. Only one subject showed a large improvement at the longer durations.

The characteristics of the VM condition were different from those of the CM. Performance seems to flatten out at the 100 msec level. There is a slight improvement in performance as the duration is increased. The effect is small, but the tendency is in the hypothesized direction.

VI. General Discussion and Conclusions

I have tried to make a detailed comparison of the auditory and the visual attention mechanisms. Recent developments in visual attention (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) and auditory attention (Ostry, Moray, and Marks, 1976) showed that a reevaluation was in order. These investigators found that subjects could successfully divide their attention with little deficit if they were well-practiced and the targets and distractors were consistently mapped. I have examined how subjects visually attend to a sequence of events that change temporally and spatially. Visual attention research has been dominated by studies that look at responses to single events. I have argued that the reponses to sequences of events are common in real life situations. Concepts of visual sequence processing were compared to the auditory attention studies that examine how the spatial and temporal pattern of speech are perceived. The apparent motion literature was briefly reviewed with regard to spatial and temporal changes.

The first experiment, the classification study, was an intitial attempt to find the features of temporal and spatial patterns that subjects utilize to discriminate one sequence from another. In a multiple regression analysis, the

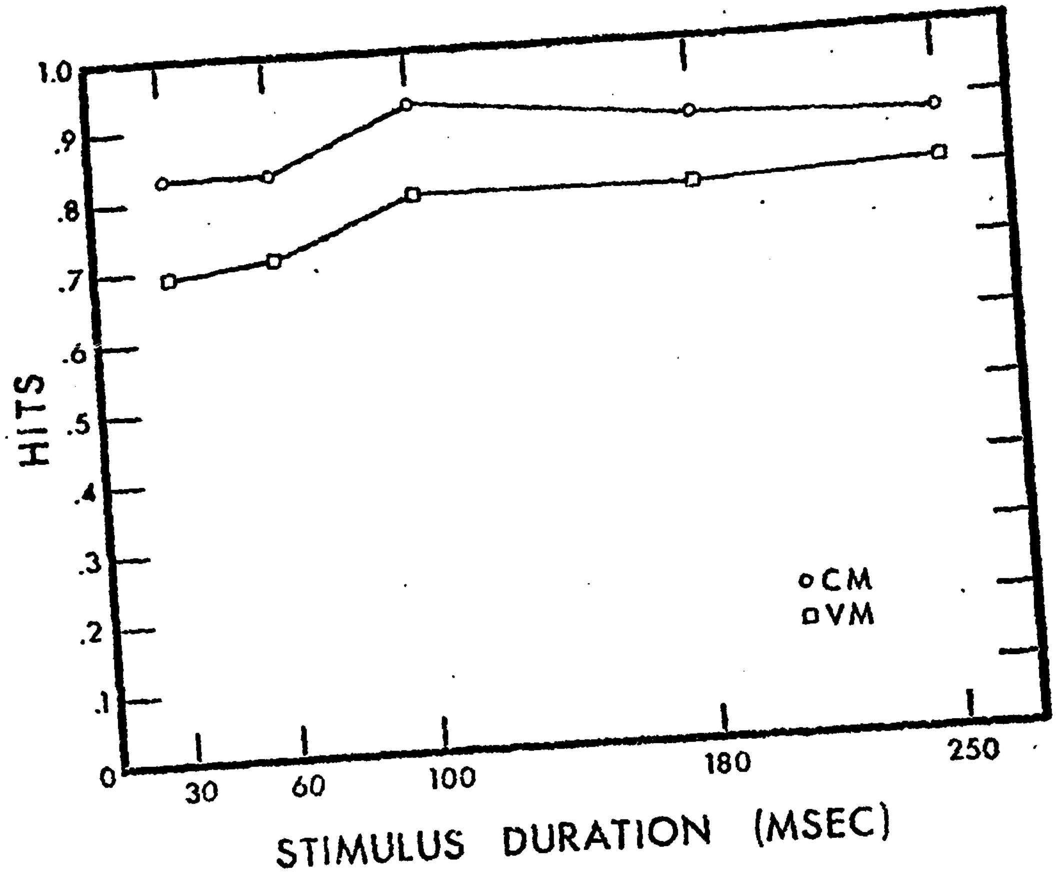


Figure 12. Data from Experiment 9: correct identification of CM and VM sequences as a function of stimulus duration.

measurements of angle changes accounted for most of the variance. Distance was a very poor determinant of error rate. It should be emphasized again that it was a correlational study and, thus, causation could not be determined. This study could be used as a first approximation to the method subjects use to identify sequences and as a guide to further research. It should also be noted that the subjects used were relatively unpracticed. The later research indicated that the methods used to perceive the sequences changed with practice.

The results from the VM experiments (Experiments 1-3) were similar to those found in auditory attention. As the channel size increased, there was a deficit in performance. Also, as the discrimination became more difficult, in Experiment 3, performance dropped. This is similar to studies using the shadowing technique where it becomes harder to choose the relevant message if the unshadowed message is similar. Movement cues did not seem to be used to try to identify the sequences.

If the experimental investigation of sequences of events was to stop here, the conclusions would be different from those argued in the next few pages. The processing of sequences would be hypothesized to be a serial process, affected by load with no apparent use of motion cues. Such a conclusion would be premature.

The last six experiments examined a series of important questions. The crucial question was: Can subjects automatically process sequences of events? Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) found that subjects could automatically process target characters with sufficient practice and consistent mapping between targets and distractors. However, the occurrence of a target character is different from the occurrence of a target sequence. In a target sequence, the defining quality is the relationship between the different events and not just the occurrence of a single event.

Can subjects automatically process sequences of events? Certainly, in these experiments, quantitative differences between the CM and the VM sequences were found. The sequences were matched for difficulty and then counterbalanced. A within subjects design was always used. Initial performance was identical within the CM and VM groups and only with practice did the differences occur. In all cases, VM performance asymptoted. Taking these facts into consideration, the quantitative differences offer strong evidence that two kinds of processing, one an automatic process, did occur. For firmer evidence, though, qualitative differences are needed.

A possible qualitative difference between CM and VM sequences was the differential use of motion and pattern cues. For sequences that are imperfectly trained (the VM sequences), it would not seem to be an efficient strategy to respond to, or allocate attention to, motion or pattern cues. The particular motion or pattern cue could always be used to identify the sequences. However, it appears to take quite a bit of effort to train oneself to respond in this manner; it was argued that the untrained subjects in Experiments 1 through 3 did not attend to the motion or pattern configurations. An easier strategy, although not quite as exact, would be to try to identify the individual events in a sequence. This is a strategy that would be easy to set up and and easy to

disband. In a VM situation, it is especially important to be able to disband a strategy. If attention is allocated to a distractor that was a target on a previous trial, and that strategy was efficient and exact, performance will suffer. Possibly only on CM trials can motion and pattern cues be used to identify the sequences. On the VM trials, a better strategy would be to respond to individual events.

Is there any evidence for this qualitative difference between the CM and VM trained sequences? In experiment 4, the CM trained targets could be picked out significantly better than the VM trained targets in a multiple sequence procedure. Movement could be the cue that enabled the better identification on the CM trials. It can be argued that this is another quantitative difference, though. In experiment 8, the relationship between the events was kept constant but the single events themselves were changed by rotating the sequences. Overall, the CM rotated targets were better identified than the VM rotated targets. If subjects had learned to respond to the motion and pattern cues, then the positive transfer to the CM rotated targets is expected. Consistent with the picture that is emerging were the results of experiment 9. It was found that the CM sequences with stimulus durations that optimized motion conditions were better identified than those sequences with long stimulus durations. For the VM sequences, it didn't seem to matter if the movement cues were lost; they weren't used to identify the sequences anyway. Overall, the effects were small, but they were all in the correct direction to support the hypothesis for qualitative differences according to movement and pattern cues. Collectively, the small effects take on more importance.

Perhaps the best evidence for qualitative differences between the CM trained sequences and the VM trained sequences was Experiment 6. There was a large deficit for the VM sequences when the channel size was increased but a small deficit for the CM sequences. Apparently, there is little effect of load for the CM trained sequences. This was a characteristic of an automatic process found by Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977).

In conclusion, it appears that an automatic process to a sequence of events can be established. Many of the characteristics of an automatic process outlined by Schneider and Shiffrin - no effect of load, the effort needed to establish it, and the parallel processing - have been identified in these experiments. Quantitative differences between CM and VM trained sequences were established. A possible qualitative difference, based on movement and pattern cues inherent to a visual sequence of events that change temporally and spatially, has also been found. There is a problem with talking about movement the way I have. In apparent motion research using three stimuli, the third stimuli can be predicted from the occurrence of the first two. The sequences used in these experiments were randomly generated so that the third could not be predicted. However, with the long practice subjects had with their particular CM target sequence, undoubtedly if the first two lines of their sequence occurred the last could be predicted. Perhaps an artificially apparent motion can be developed with practice.

References

Atkinson, R. C., Holmgren, J. E., & Juola, J. F. Processing time as influenced by the number of elements in a visual display. Perception & Psychophysics, 1969, 6, 321-326.

Bell, H. H., & Lappin, J. S. Sufficient conditions for the discrimination of motion. Perception & Psychophysics, 1973, 14, 45-50.

Boring, E. G. Sensation and perception in the history of experimental psychology. New York: Appleton-Century-Crofts, 1942.

Broadbent, D. E. Perception and communication. New York: Pergamon Press, 1958.

Broadbent, D. E. Decision and stress. London: Academic Press, 1971.

Bushbaum, W. H., & Mayzner, M. S. The effect of line length on sequential blanking. Psychonomic Science, 1969, 15, 111-112.

Cherry, C. Some experiments on the reception of speech with one and with two ears. Journal of the Acoustical Society of America, 1953, 25, 975-979.

Colquhoun, W. P., & Baddeley, A. D. Role of pretest expectancy in vigilance decrement. Journal of Experimental Psychology, 1964, 68, 156-160.

DeSilva, H. R. An experimental investigation of the determinants of apparent visual movement. American Journal of Psychology, 1926, 37, 469-501.

Deutsch, J. A., & Deutsch, D. Attention: Some theoretical considerations. Psychological Review, 1963, 70, 80-90.

Eriksen, B. A., & Eriksen, C. W. Effects of noise letters upon the identification of a target letter in a nonsearch task. Perception & Psychophysics, 1974, 16, 143-149.

Eriksen, C. W., & Hoffman, J. E. Temporal and spatial characteristics of selective encoding from visual displays. Perception & Psychophysics, 1972, 12, 201-204.

Eriksen, C. W., & Hoffman, J. E. The extent of processing of noise elements during selective encoding from visual displays. Perception & Psychophysics, 1973, 14, 155-160.

Fehrer, E., & Raab, D. Reaction time to stimuli masked by metacontrast. Journal of Experimental Psychology, 1962, 63, 143-147.

Fox, J. Recognition and attention. Quarterly Journal of Experimental Psychology, 1974, 26, 144-157.

Gardner, G. T. Evidence for independent parallel channels in tachistoscope perception. Cognitive Psychology, 1973, 4, 130-155.

Graham, C. H. Perception of movement. In C. H. Graham (ED.), Vision and visual perception. New York: Wiley, 1965.

Greenspon, T. C. Beta movement in three-light displays. Unpublished doctoral dissertation, University of Illinois, 1969.

Hall, R., & Swane, D. Memory in a bisensory selective attention task. Quarterly Journal of Experimental Psychology, 1973, 25, 309-315.

Kahneman, D. An onset-onset law for one case of apparent motion and metacontrast. Perception & Psychophysics, 1967, 2, 577-584.

Kahneman, D. Attention and effort. Englewood Cliffs, N. J.: Prentice-Hall, 1973.

Kahneman, D., & Wolman, R. E. Stroboscopic motion: Effects of duration and interval. Perception & Psychophysics, 1970, 8, 161-164.

Koffka, K. Principles of Gestalt Psychology. New York: Harcourt, Brace and Company, 1935.

Kolers, P. A. The illusion of movement. Scientific American, 1964, 211, (#4), 98-106.

Korte, A. Kinematoskopische Untersuchungen. Zeitschrift fur Psychologie, 1915, 72, 193-296.

Kristofferson, M. W. When item recognition and visual search function are similar. Perception & Psychophysics, 1972, 12, 379-384.

Lappin, J. S., & Bell, H. H. Perceptual differentiation of sequential visual patterns. Perception & Psychophysics, 1972, 12, 129-134.

Lappin, J. S., Bell, H. H., Harm, O. J., & Kottas, B. On the relation between time and space in the visual discrimination of velocity. Journal of Experimental Psychology: Human Perception and Performance, 1975, 1, 383-394.

Lappin, J. S., & Bell, H. H. The detection of coherence in moving random-dot patterns. Vision Research, 1976, 16, 161-168.

Lawson, E. A. Decisions concerning the rejected channel. Quarterly Journal of Experimental Psychology, 1966, 18, 260-265.

Mayzner, M. S., Tresselt, M. E., & Cohen, A. Preliminary findings on some effects of very fast sequential input rates on perception. Psychonomic Science, 1966, 6, 513-514.

Moray, N. Attention: Selective processes in vision and hearing. London: Hutchinson Educational, 1969.

Neisser, U. Cognitive psychology. New York: Appleton-Century-Crofts, 1967.

Neisser, U., & Becklen, R. Selective looking: Attending to visually specified events. Cognitive Psychology, 1975, 7, 480-494.

Ninio, A., & Kahneman, D. Reaction time in focused and in divided attention. Journal of Experimental Psychology, 1974, 103, 394-399.

Ostry, D., Moray, N., & Marks, G. Attention, practice, and semantic targets. Journal of Experimental Psychology: Human Perception and Performance, 1976, 3, 326-336.

Pohlmann, L. D., & Sorkin, R. D. Simultaneous three-channel signal detection: Performance and criterion as a function of order of report. Perception & Psychophysics, 1976, 20, 179-186.

Restle, F. Coding theory of the perception of motion configuration. Psychological Review, 1979, 86, 1-24.

Schiller, P. H., & Smith, M. Detection in metacontrast. Journal of Experimental Psychology, 1966, 71, 32-39.

Schneider, W., & Shiffrin, R. M. Controlled and automatic human information proceesing: I. Detection, search and attention. Psychological Review, 1977, 84, 1-66.

Shaffer, L. H., & Hardwick, J. Monitoring simultaneous auditory messages. Perception & Psychophysics, 1969, 6, 401-404.

Shiffrin, R. M., & Gardner, G. T. Visual processing capacity and attentional control. Journal of Experimental Psychology, 1972, 93, 72-82.

Shiffrin, R. M., Gardner, G. T., & Allmeyer, D. H. On the degree of attention and capacity limitation in visual processing. Perception & Psychophysics, 1973, 14, 231-236.

Shiffrin, R. M., & Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. Psychological Review, 1977, 84, 127-190.

Simpson, P. J. High-speed scanning: Stability and generality. Journal of Experimental Psychology, 1972, 96, 239-246.

Sperling, G., Budiansky, J., Spivak, J. G., and Johnson, M. C. Extremely rapid visual search: The maximum rate of scanning letters for the presence of a numeral. Science, 1971, 174, 307-311.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Swanson, J. M., & Briggs, G. E. Information processing as a function of speed versus accuracy. Journal of Experimental Psychology, 1969, 81, 223-229.

Treisman, A. M. Contextual cues in selective attention. Quarterly Journal of Experimental Psychology, 1960, 12, 242-248.

Treisman, A. M. Monitoring and storage of irrelevant messages in selective attention. Journal of Verbal Learning and Verbal Behevior. 1964a, 3, 449-459.

Treisman, A. M. Verbal cues, language and meaning in selective attention. American Journal of Psychology, 1964b, 77, 206-219.

Treisman, A. M. Strategies and models of selective attention. Psychological Review, 1969, 3, 282-299.

Treisman, A. M., & Fearnley, S. Can simultaneous speech be classified in parallel? Perception & Psychophysics, 1971, 10, 1-7.

Treisman, A. M., Riley, J. Is selective attention selective perception or selective response? A further test. Journal of Experimental Psychology, 1969, 79, 1-17.

Wertheimer, M. Experimentelle Studien ueber das Sehen von Bewegung. Zeitschrift fur Psychologie, 1912, 61, 161-265.

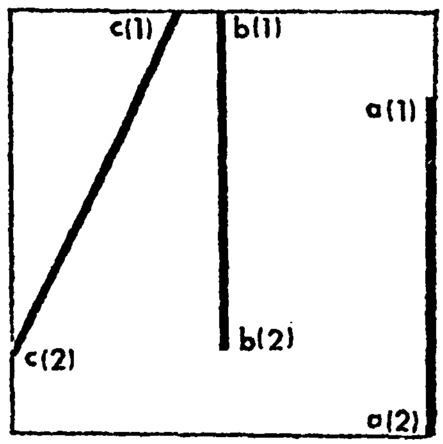


Figure 13. An example of a sequence used to specify how the predictor variables were calculated.

Appendix

Refer to figure 13. In this sequence, line a appeared first followed by b and then c. Each end of every line is labelled. The sequence occurred in a 60 x 60 unit matrix. The distances were measured in those units. Thus, the ends of each of the lines could be described by an ordered pair. For this example, the coordinates are:

a(1) = (60,48)
a(2) = (60,0)
b(1) = (30,60)
b(2) = (30,12)
c(1) = (24,60)
c(2) = (0,12)

First, the Euclidean distances from lines a to b were computed and then the distances from line b to line c were computed for eight distances altogether. From the example, let

d(1) = distance from a(1) to b(1)
d(2) = distance from a(1) to b(2)
d(3) = distance from a(2) to b(1)
d(4) = distance from a(2) to b(2)
d(5) = distance from b(1) to c(1)
d(6) = distance from b(1) to c(2)
d(7) = distance from b(2) to c(1)
d(8) = distance from b(2) to c(2).

Next, the minima and maxima were found for each gap. Let

d(9) = min(d(1),d(2))
d(10) = min(d(3),d(4))
d(11) = max(d(1),d(2))
d(12) = max(d(3),d(4))
d(13) = min(d(5),d(6))
d(14) = min(d(7),d(8))
d(15) = max(d(5),d(6))
d(16) = max(d(7),d(8))

Then, the average distance that a dot in the middle of the line travelled was found by averaging the minima and maxima for each gap. Let

d(17) = (d(9) + d(10)) / 2
d(18) = (d(11) + d(12)) / 2
d(19) = (d(13) + d(14)) / 2
d(20) = (d(15) + d(16)) / 2.

In the text, d(17) corresponded to the minimum distance of gap 1, d(18) was the maximum distance of gap 1, d(19) was the minimum distance of gap 2, and d(20) was the maximum distance of gap 2.

As an example of the discrepancy measurement, again refer to figure 12 and the distances used in the previous example. The discrepancy between the top (left) and bottom (right) of each line was determined using the previously computed distances. Let

$$g(1) = abs(d(9) - d(10))$$
$$g(2) = abs(d(11) - d(12))$$
$$g(3) = abs(d(13) - d(14))$$
$$g(4) = abs(d(15) - d(16))$$

where abs is the absolute value. From the text, g(1) is the minimum discrepancy of gap 1, g(2) is the maximum discrepancy of gap 2, g(3) is the minimum discrepancy of gap 2, and g(4) is the maximum discrepancy of gap 2. The minima and maxima refer to the distances that were used to compute the discrepancies. The minimum discrepancy of gap 1 is not necssarily less than the maximum discrepancy of gap 1.

The angle measurement was found by finding the acute angle of the intersection of lines a and b and lines b and c. If the lines did not intersect the angle was 0 degrees.

ONR Distribution List
Schneider March 10, 1980

A. Bachrach, Environmental Stress, Naval Med Res Inst, Bethesda, MD
T. Berghage, Naval Health Res Cntr, San Diego
R. Breaux, NAVTRAEQUIPCEN, Orlando
Chief of Naval Educ & Training Liason Office, AFHRL, Williams AFB
L. Dean, Naval Submarine Med Res Lab, Groton, CT
R. Elster, Admin Sciences, Naval Postgraduate School, Monterey, CA
P. Federico, Navy Personnel R&D Cntr, San Diego
P. Foley, Navy Personnel R&D Cntr, San Diego
J. Ford, Navy Personnel R&D Cntr, San Diego
R. Gibson, Bureau of Medicine and Surgery, Washington
G. N. Graine, Personnel & Training Analysis Office, Washington
S. D. Harris, Naval Air Dev Cntr, Warminster, PA
P. R. Harrison, US Naval Academy, Annapolis
W. Helm, Univ So Dakota, Vermillion
L. Hitchcock, Naval Air Dev Cntr, Warminster, PA
C. W. Hutchins, Naval Air Sys Com Hq, Washington
R. S. Kennedy, Naval Aerospace Med Res Lab, New Orleans
N. J. Kerr, Naval Air Station Memphis, Millington, TN
L. Kroeker, Navy Personnel R&D Cntr, San Diego
W. L. Maloy, Naval Training Com, Pensacola, FL
K. Marshall, Scientific Advisor to DCNO(MPT), Washington
R. L. Martin, Newport News Shipbuilding and Drydock, Newport News, VA
J. McBride, Navy Personnel R&D Cntr, San Diego
G. Moeller, Naval Submarine Med Res Lab, Groton, CT
W. Montague, Navy Personnel R&D Cntr, San Diego
W. Moroney, Naval Postgraduate School, Monterey, CA
Commanding Officer, US Naval Amphibious School, Coronado, CA
Library, Naval Health Res Cntr, San Diego
Naval Med R&D Com, Natl Naval Med Cntr, Bethesda, MD
T. M. I. Yellen, Navy Personnel R&D Cntr, San Diego
Library, Navy Personnel R&D Cntr, San Diego
Technical Director, Navy Personnel R&D Cntr, San Diego
Director, Navy Personnel R&D Cntr, Washington Liason Office, Washington Navy Yard, DC
Commanding Officer, NRL, Washington
Psychologist, ONR Branch Office, Boston
Psychologist, ONR Branch Office, Chicago
ONR, Arlington
Personnel & Training Res Programs, Arlington
Psychologist, ONR Branch Office, Pasadena, CA
Office of the Chief of Naval Operations, Res, Dev, & Studies Branch, Washington
D. F. Parker, Navy Personnel R&D Cntr, San Diego
F. C. Petho, Naval Aerospace Med Res Lab, Pensacola
G. Poock, Naval Postgraduate School, Monterey, CA
R. W. Remington, NAMRL, Pensacola
B. Rimland, Navy Personnel R&D Cntr, San Diego
S. Schiflett, US Navy Air Test Cntr, Patuxent River, MD
R. G. Smith, Office of Chief of Naval Operations, Washington
A. F. Smode, Dept. of the Navy, Orlando
R. Sorensen, Navy Personnel R&D Cntr, San Diego
W. G. Thomson, Naval Ocean Systems Cntr, San Diego
R. Weitzman, US Naval Postgraduate School, Monterey, CA
H. M. West III, Program Dev Branch, Arlington Annex, Washington

R. Wisher, Navy Personnel R&D Cntr, San Diego
M. F. Wiskoff, Navy Personnel R&D Cntr, San Diego
Technical Director, US Army Res Inst for the Behav & Soc Sciences, Alexandria
HQ USAREUE & 7th Army, USAAREUE Director of GED, APO NY
J. Barber, HQS, Dept. of the Army, Washington
G. W. Bloedorn, US Army TRADOC Systems Analysis Activity, WSMR, NM
R. Dusek, Army Res Inst, Alexandria
B. J. Farr, Army Res Inst, Alexandria
E. Johnson, Army Res Inst, Alexandria
M. Kaplan, Army Res Inst, Alexandria
M. Katz, Army Res Inst, Alexandria
Director, US Army Human Eng Labs, Aberdeen Proving Ground, MD
H. F. O'Neil, Jr., Army Res Inst, Alexandria
R. Ross, Army Res Inst for the Soc and Behav Sciences, Alexandria
R. Sasmor, Army Res Inst for the Behav & Soc Sciences, Alexandria
Commandant, US Army Inst of Admin, Ft Benjamin Harrison, IN
F. Steinheiser, Army Res Inst, Alexandria
J. Ward, Army Res Inst, Alexandria
AF Human Resources Lab, Brooks AFB, TX
USAF Office of Scientific Res, Bolling AFB, Washington
Air Univ Library, Maxwell, AFB, AL
E. A. Alluisi, Brooks AFB, TX
G. Haddad, Life Sciences Directorate, Bolling AFB, Washington
R. G. Hughes, Williams AFB, AZ
Res and Measurement Div, AFMPC/MPCYPR, Randolph AFB, TX
M. Ree, AFHRL/MP, Brooks AFB, TX
M. Rockway, Lowry AFB, CO
F. Schufletowski, Randolph AFB, TX
3700 TCHTW/TTGH Stop 32, Sheppard AFB, TX
J. A. Thorpe, Naval War College, Providence, RI
B. K. Waters, Maxwell AFB, AL
H. W. Greenup, Educ Cntr, MCDEC, Quantico, VA
HQ, US Marine Corps, Washington
Special Asst for Marine Corps Matters, ONR, Arlington
A. L. Slafkosky, Scientific Advisor, Washington
Defense Doc Cntr, Alexandria
D. Fletcher, Adv Res Proj Agency, Arlington
Military Asst for Training & Personnel Tech, Office of the Under Sec of Defense for Res & Eng, Washington
S. Chipman, Natl Inst of Educ, Washington
J. Lehnus, US Office of Personnel Management, Chicago
J. I. Lipson, NSF, Washington
A. R. Molnar, NSF, Washington
Personnel R&D Cntr, Office of Personnel Management, Washington
H. W. Sinaiko, Manpower Res and Advisory Services, Smithsonian Inst, Alexandria
F. Withrow, US Office of Educ, Washington
J. L. Young, NSF, Washington
E. B. Andersen, Studiestraede 6, Denmark
J. R. Anderson, Carnegie Mellon Univ
J. Annett, Univ of Warwick, England
M. Atwood, Science Applications Inst, Englewood, CO
1 Psychological Res Unit, Dept. of Defense, Australia
A. Baddeley, Med Res Council Applied Psych Unit, England
P. Baggett, Univ of Denver
J. Beatty, Univ of California, Los Angeles

N. A. Bond, Sacramento State College
L. Bourne, Univ of Colorado, Boulder
B. Buchanan, Stanford Univ
J. B. Carroll, Univ of No. Carolina, Chapel Hill
Charles Myers Library, Livingstone House, Stratford, England
W. Chase, Carnegie Mellon Univ
M. Chi, Univ of Pittsburgh
W. Clancey, Stanford Univ
A. M. Collins, Bolt Beranek & Newman, Inc, Cambridge, MA
L. A. Cooper, Cornell Univ
M. P. Crawford, APA, Washington
K. B. Cross, Anacapa Sciences, Santa Barbara, CA
E. Donchin, Univ of Illinois, Champaign
J. C. Eggenberger, Directorate of Personnel Applied Res, Natl Defense HQ, Ottawa, Canada
ERIC Facility-Acquisitions, Bethesda, MD
R. L. Ferguson, ACT Program, Iowa City, IA
E. A. Fleishman, Adv Res Resources Organ, Washington
J. R. Frederiksen, Bolt Beranek & Newman, Cambridge, MA
A. Friedman, Univ of Alberta, Canada
R. E. Geiselman, Univ of California, Los Angeles
R. Glaser, Univ of Pittsburgh
M. D. Glock, Cornell Univ
F. E. Gomer, McDonnell Douglas Astronautics Co., St. Louis
D. Gopher, Technion-Israel Inst of Technology, Israel
J. G. Greeno, Univ of Pittsburgh
H. Hawkins, Univ of Oregon, Eugene
B. Hayes-Roth, Rand Corp, Santa Monica, CA
F. Hayes-Roth, Rand Corp, Santa Monica, CA
J. R. Hoffman, Univ of Delaware, Newark
L. Humphreys, Univ of Illinois, Champaign
Library, HumRRO/Western Div, Carmel, CA
E. Hunt, Univ of Washington, Seattle
D. H. Jones, Educ Testing Service, Princeton
Journal Supplement Abstract Service, APA, Washington
S. W. Keele, Univ of Oregon, Eugene
W. Kintsch, Univ of Colorado, Boulder
D. Kieras, Univ of Arizona, Tuscon
S. Kosslyn, Harvard Univ
M. Kroger, Palos Verdes Estates, CA
J. Larkin, Carnegie Mellon Univ
A. Lesgold, Univ of Pittsburgh
C. Lewis, Rijks Universiteit Groningen, Netherlands
J. Lumsden, Univ of Western Australia
M. Miller, Texas Instruments, Dallas, TX
A. Munro, Behav Tech Labs, Redondo Beach, CA
D. A. Norman, Univ of California, San Diego
M. R. Novick, Univ of Iowa, Iowa City
J. A. Paulson, Portland State Univ
L. Petrullo, Arlington
M. Polson, Univ of Colorado, Boulder
P. Polson, Univ of Colorado, Boulder
D. M. Ramsey-Klee, R-K Res & System Design, Malibu, CA
M. L. Rauch, Bundesministerium der Verteidigung, Germany
A. M. Rose, Amer Inst for Res, Washington

E. Z. Rothkopf, Bell Labs, Murray Hill, NJ
D. Rumelhart, Univ of California, San Diego
R. J. Seidel, Instructional Tech Grp HUMRRO, Alexandria
Committee on Cognitive Res, Soc Science Res Council, New York
R. Smith, Rutgers Univ
R. Snow, Stanford Univ
K. T. Spoehr, Brown Univ
R. Sternberg, Yale Univ
A. Stevens, Bolt Beranek & Newman, Cambridge, MA
D. Stone, SUNY, Albany
P. Suppes, Stanford Univ
H. Swaminathan, Univ of Massachusetts
K. Tatsuoka, Univ of Illinois, Urbana
C. J. Theisen, Jr., New Hope, PA
D. Thissen, Univ of Kansas
J. Thomas, IBM Thomas J. Watson Res Cntr, Yorktown Hts, NY
P. Thorndyke, Rand Corp, Santa Monica
D. Towne, Univ of So. California, Redondo Beach
J. Uhlaner, Perceptronics Inc, Woodland Hills, CA
B. J. Underwood, Northwestern Univ, Evanston, IL
P. Weaver, Harvard Univ
D. J. Weiss, Univ of Minnesota
G. Weltman, Perceptronics Inc, Woodland Hills, CA
K. T. Wescourt, Rand Corp, Santa Monica
S. E. Whitely, Univ of Kansas
C. Wickens, Univ of Illinois, Champaign
W. Wildgrube, Streitkraefteamt, West Germany
J. A. Woodward, Univ of California

Recent Human Attention Research Laboratory Reports

7901 Eberts, R. The automatic and controlled processing of sequences of events.
8001 Schneider, W. and Fisk, A. D. Independence of foveal retinal locus and visual detection paradigm.
8002 Schneider, W. and Fisk, A. D. Dual task automatic and controlled processing in visual search, can it be done without cost?
8003 Eberts, R. and Schneider, W. The automatic and controlled processing of temporal and spatial patterns.
8004 Schneider, W. and Fisk, A. D. Visual search improves with detection searches, declines with nondetection search.
8005 Schneider, W. and Fisk, A. D. Degree of consistent training and the development of automatic processing.
8006 Fisk, A. D. and Schneider, W. Controlled and automatic processing during tasks requiring sustained attention: A new approach to vigilance.
8007 Fisk, A. D. and Schneider, W. On the learning of distractors during controlled and automatic processing.
8008 Schneider, W. and Eberts, R. Automatic processing and the unitization of two features.
8009 Schneider, W. and Fisk, A. D. Context dependent automatic processing. (in preparation)